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**BENEFITS OF VTOL AIRCRAFT IN OFFSHORE PETROLEUM  
LOGISTICS SUPPORT**

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## TABLE OF CONTENTS

	<u>Page</u>
SUMMARY	1
INTRODUCTION	4
TRENDS IN OFFSHORE ACTIVITY	9
OFFSHORE SUPPORT REQUIREMENTS	14
LOGISTICS SUPPORT VEHICLES	22
BENEFITS OF ADVANCED VTOL AIRCRAFT	32
CONCLUSIONS	39
REFERENCES	42

## SUMMARY

The expanding search for petroleum throughout the world has created a growing need for logistics support of exploration and production activities. With the number of offshore wells expected to double by 1985, and with the offshore distances increasing rapidly, the requirement for helicopters to transfer men and supplies to and from the oil and gas rigs should continue to increase. Over 20% of the civil helicopters produced in the next decade are expected to be utilized for this purpose.

Although marine vessels are widely used in support of offshore petroleum, several factors have led to replacement by helicopters in a growing number of operations. The much higher speed of helicopters provides better emergency evacuation capability, faster parts delivery, and increased productivity of the personnel being transferred. Beyond about 50 miles, helicopters are the most economical means of transporting crews. They are often used even at shorter distances, because of strong worker preference for the speed and comfort of the helicopter. Use of boats is particularly limited in rough weather such as that frequently experienced in the North Sea.

A study was performed to determine the mission suitability and potential economic benefits of advanced VTOL aircraft in offshore petroleum operations. The North Sea and the Gulf of Mexico were selected for analysis of advanced helicopter, tilt rotor, and lift/cruise fan aircraft as future replacements for current helicopters. In both markets, present use of helicopters is extensive, and projections for the 1980's indicate a requirement for many more.

The study indicates that there is a strong need for advanced VTOL aircraft. Performance limitations of current helicopters result in offloading of passengers to provide sufficient fuel to reach the more distant rigs even today. This greatly increases the unit operating cost and the number of aircraft required. As offshore distances increase, aircraft with greater cruise efficiency are needed to satisfy mission requirements. Helicopters now in development will provide better range/payload capability as well as 20% to 30% increases in cruise speed. This will provide significant improvements in operating economics. Further gains are possible through advanced helicopter technology now in progress.

Future petroleum activity 200 to 500 miles offshore will require even greater improvements in VTOL aircraft efficiency. Concepts such as the tilt rotor and lift/cruise fan are very promising. Due to good fuel utilization efficiency, greatly extended range of operation is possible without refueling. The cruise speed of these concepts is also greater than that of either current or advanced helicopters. The tilt rotor provides nearly twice the range of the helicopter for the same fuel and trip time. The lift/cruise fan cruises at three times the speed of the helicopter and also yields a greater range/payload capability.

The greater productivity of such aircraft will provide many benefits. The aircraft operator will benefit through reduced capital investment in aircraft, spares, ground equipment and pilot training. Operating costs will be reduced by 20% to 50%, depending upon mission requirements. The petroleum industry will gain increased oil rig productivity and improved logistics support. Most importantly, the availability of petroleum may

be increased by the ability to economically support exploration and production further offshore and in more remote locations.

Each type of VTOL aircraft, as well as the boat, has a useful role to fill in offshore oil support. For short ranges in calm seas, for pipe laying operations, or for large cargo movement, the boat is the most effective mode of transportation. Beyond about 50 miles offshore or in rough weather, aircraft are more efficient, particularly for movement of personnel and priority cargo and for emergency operations. Tilt rotor or lift/cruise fan aircraft cannot economically replace helicopters in the short-range operations. There will be a continuing need for advanced helicopters for movement of small parties of executive and specialist personnel during on-site inspections, and for crew change operations on the many rigs close to shore. The more distant operations will best be performed with either the tilt rotor or lift/cruise fan, or possibly with improved compound helicopters. The ideal fleet may well consist of some mix of the different aircraft concepts.

## INTRODUCTION

In the next ten years the U. S. petroleum industry must find and develop nearly 50% more oil than it did during the past 15 years to meet our nation's increasing energy needs.<sup>(1)</sup> Projections by the National Petroleum Council indicate a domestic oil consumption of about 26 million barrels per day by 1985.<sup>(2)</sup> This is 40% greater than the U. S. consumption in 1975. Such growth must be met by increased domestic oil production, or by oil imports.

While the U. S. had a net oil import requirement of only 1 billion barrels in 1968, over 2 billion barrels will be imported in 1975. This is approximately 40% of the current U. S. consumption. The National Petroleum Council has projected a range of oil import needs through 1985 based on combinations of various values for energy supply and demand factors. The most likely combinations indicate potential imports of from 5 to 7 billion barrels in 1985, despite increased use of coal and nuclear energy by electric utilities.

A continuation of the 5 billion barrel import rate would result in a \$65 billion annual cash drain from the U. S. at current oil prices. With a 5% average annual inflation in the price of foreign oil, the U. S. would be paying petroleum exporting countries over \$100 billion per year by 1985. The total for all of the oil importing countries, who already experienced a trade deficit with the oil producers of \$65 billion in 1974,<sup>(3)</sup> will be many times that figure. Thus, there are strong incentives in the U. S. and elsewhere to develop new sources of petroleum.

Some of the most promising areas in the worldwide search for oil and gas today lie offshore. In 1974, offshore rigs produced 20% of the world's total oil output of 50 million barrels per day. By 1985, offshore sources may account for 25 million barrels per day. Over 400 drilling rigs are working the world's continental shelves.<sup>(1)</sup> More than a quarter of these are in U. S. waters, principally in the Gulf of Mexico. Major new fields have recently been found off Brazil, in Indonesia, and in the North Sea. Promising finds have occurred throughout the world. Stimulated by the U. S. drive toward energy self-sufficiency, interest is increasing on the Atlantic and Pacific Coasts, the Gulf of Alaska, and the Beaufort Sea.

As of January 1, 1974, 60 maritime nations either had or were about to have offshore petroleum production. Offshore exploration activities were being conducted in at least 55 additional countries. An estimated 18% of proven recoverable world reserves and as much as 60% of undiscovered recoverable reserves may be offshore.<sup>(4)</sup> Median estimates of the U. S. Geological Survey indicate that about 100 billion barrels of oil and 600 trillion cubic feet of gas remain to be discovered on the U. S. continental shelf, about 17% of the world's undiscovered offshore total. On the other hand, estimates by a major U. S. oil company place the total recoverable resources off U. S. coasts at only about one-half the U.S.G.S. value,<sup>(5)</sup> but also estimate this to be three to four times the recoverable resources onshore.

The push for oil exploration and production offshore and in remote locations such as Indonesia and Alaska's North Slope have created tremendous demands for logistics support. There are perhaps 20,000 men working the



offshore rigs around the world. These men must be transported to and from the rigs every week or two, with an equal number replacing them. Equipment and supplies must be provided on a timely basis to maintain continuous operation. Rapid transfer of supervisory and trouble-shooting personnel to and from the rigs, and emergency evacuation of sick or injured workers are frequently required.

The petroleum industry has found that much of this support requirement can be met very effectively by helicopters, because of their advantages over boats in speed, operating economics, and comfort. The result has been a rapid expansion in the use of helicopters to transport men and equipment to the operating sites, and over 20% of all civil helicopters produced now and in the next decade are expected to be employed in support of the petroleum industry. (6,7)

In some regions the helicopter is the most viable means of transportation. One example is Indonesia, which is experiencing continued demand for new drilling sites all along the 3000 mile chain of islands. The logistics support of these operations is greatly complicated by the terrain, which is mountainous and is covered with dense jungle and numerous unbridged rivers. Indonesia's ground transportation system is underdeveloped and in places nonexistent, particularly on the outer islands. Thus, the helicopter offers the only practical means of reaching some of the drilling sites both offshore and in the jungle.

In other areas, ground or water transportation is readily available. In such cases the preferred mode of transportation is determined by mission effectiveness and economics. Examples of this are found in the

Gulf of Mexico, off the Southern California Coast, and in the Persian Gulf and the North Sea. Both boat and helicopter are used in these areas.

Future requirements for offshore oil support will be dictated by the pace of drilling activity, by trends toward increasing offshore distances, and by labor demands for more frequent returns to home base. Site-related factors such as weather conditions, political jurisdictions, and proximity to major population centers will be important in determining the extent of aircraft usage and geographical preferences for particular aircraft performance characteristics.

A study of the benefits of VTOL aircraft in the offshore application has been made to assist the identification of promising aircraft technologies for NASA to pursue. Included is an examination of the current market in which helicopters and boats provide support service, and also an analysis of the future potential for advanced VTOL aircraft with greater speed and range than current helicopters. The study addressed the general mission suitability and economics of advanced helicopters as well as those of tilt rotor and lift/cruise fan aircraft. Comparisons were made of fleet size and capital investment requirements, of the productivity and operating costs of the candidate concepts, and of benefits to the petroleum industry resulting from the special characteristics of each aircraft.

Two offshore petroleum markets were selected for the analysis. In both the Gulf of Mexico and the North Sea, helicopters are used extensively at the present time. Projected aircraft requirements for 1985 are much greater, as the number of offshore wells has been estimated to be several

times that of today.<sup>(2)</sup> There are, however, important differences in the mission characteristics for the two areas, primarily in range and weather conditions, which determine the preferred aircraft design and performance characteristics.

## TRENDS IN OFFSHORE ACTIVITY

In the past the offshore petroleum industry has moved out from inland and protected waters in an evolutionary manner. The technology resulting from this steady growth has enabled the industry to open new fields far offshore and in unprotected waters around the world. Offshore operations are expensive, however, with costs running two to five times those of onshore operations. The costs are even greater in the harsh environment of the North Sea and the Gulf of Alaska.

### Offshore Operations in the United States

Most of the current U. S. offshore petroleum exploration and production activity is concentrated in the Gulf of Mexico, off Louisiana and Texas. Other U. S. offshore activity is located along the Southern California Coast and in the Cook inlet area of Southern Alaska. Recent geological surveys indicate potentially large oil and gas fields along the Atlantic, Pacific, and Alaskan Coasts. One of the largest of these fields is thought to be located off the north shore of Alaska. However, the technical problems resulting from foul weather and ice flows in the Arctic Ocean and Beaufort Sea will probably prevent any significant development during the 1980's.

The Mobil Oil Company estimates the total recoverable reserves located on the continental shelf of the U. S. at 48 billion barrels of oil.<sup>(5)</sup> About 14 billion barrels are thought to be located in the Gulf of Mexico and a like amount in the Gulf of Alaska, mostly at water depths of less than 1500 feet. In addition, Atlantic reserves are estimated at 6 billion barrels and Pacific reserves at 14 billion barrels,

based on exploration in water depths ranging to 6000 feet. Numerous geologic surveys have been conducted along the Atlantic and Pacific Coasts and in the Gulf of Alaska. The rate which these areas will be opened for development is dependent to a large extent on political factors in addition to the normal economic and technical considerations.

#### Gulf of Mexico

The boundaries of current and future offshore activity in the Gulf of Mexico are shown in Figure 1. Most of the 100 drilling rigs now operating are in offshore Louisiana waters, although several large new areas were recently opened for exploration of Florida and Texas. Future activity will expand into the potential new lease areas shown in Figure 1.<sup>(8)</sup> Extending operations into this area would increase maximum water depth from 600 to 1500 feet and would increase the distance from shore bases well beyond the 150 miles to which current activity is restricted.

There are in excess of 6600 producing oil wells and 2700 gas wells offshore in the Gulf of Mexico. New wells were being drilled at the rate of over 900 per year in 1973, and activity is at a much higher rate in 1975. The number of drilling rigs in the Gulf is now about 100, an increase of 20 percent from 1974.<sup>(9)</sup>

#### Southern California

Activity off the Southern California Coast is shown in Figure 2. Present offshore operations are centered around the Santa Barbara Channel. Surveys of the Outer Santa Barbara Channel and the Pacific Ocean near San Diego have been conducted and drilling is expected to begin as soon as leases and government permission can be obtained.

Most of the 2800 producing oil wells are within 35 miles from shore and the majority of production islands are less than 10 miles from shore. However, with the opening of the outer channel the offshore distances will reach 50 to 100 miles. These offshore operations will establish a production distribution network which will eventually provide a basis for more distant offshore development in waters as much as 6000 feet deep.

#### Offshore Alaska

Current and future Alaskan offshore activity is shown on Figure 3. Present activity is centered in the Cook Inlet on the southern coast of Alaska, where recovery operations have had to overcome icy waters and very high tides. Surveys indicate approximately 10 billion barrels of oil under the Gulf of Alaska and 4 billion barrels in the Bristol Bay area.<sup>(2)</sup> Cost of operations in these areas will be significantly higher than those in the Cook Inlet and the distances from current population centers would be as much as 100 to 200 miles.

The oil reserves in the offshore area of the North Slope are estimated as high as 48 billion barrels. However, the extreme cold, the stormy and icy seas, and the limited drilling season make exploration and production operations extraordinarily costly and difficult. The two greatest offshore obstacles are ice flows and polar pack movements that often scour the sea bottoms. Due to the enormous costs that would be required and the time needed to develop the required technology to operate under these conditions, it is unlikely that any of this potential will be developed during the next 15 years.

### Atlantic Coast

The location of several promising potential gas and oil development areas off the Atlantic Coast are shown in Figure 4. The initial exploration is expected to begin in the Georges Bank area, where Canadian oil companies have already located two gas fields off the coast of Nova Scotia. Offshore distances from the North Atlantic and Middle Atlantic states are expected to range from 30 to 150 miles with somewhat greater distances and water depths off the Florida Coast.<sup>(10)</sup> The main obstacles to Atlantic exploration and development are jurisdictional disputes between the Atlantic Coast states and the federal government over control of the oil and gas deposits and environmental concern over drilling off the Atlantic Coast.

### North Sea Petroleum Operations

The discovery of the Ekofisk oil field by Norway in 1969 gave a rapid stimulus to exploration and development in the North Sea. Since that time two more major oil fields have been discovered: the Forties Field about 120 miles east of Aberdeen, Scotland, and the giant British-Norwegian fields which are more than 150 miles northeast of the Shetland Islands. Figure 5, from reference 11, shows current activity in the British and Norwegian sectors and the location of the major oil fields and some of the exploratory activity out of the main supply port of Aberdeen and the forward staging area of Sumburgh. Distances range from slightly less than 100 miles to nearly 200 miles.

A large number of oil discoveries near these fields are awaiting production. Ultimate North Sea reserves have been estimated to be on the order of 42 billion barrels of oil and 110 trillion cubic feet of

gas.<sup>(12)</sup> It has been further estimated that the North Sea will be producing 4 million barrels of oil per day in 1985.

Potential future North Sea activity in relation to current activity is shown on Figure 6. In 1973, surveys of the Norwegian continental shelf were made at distances out to 200 miles offshore.<sup>(13)</sup> As a result of these surveys several blocks have been leased near the Arctic Circle about 100 miles off the coast. In addition a high level of future activity in the British sector of the North Sea was assured by the 1972 award of 246 blocks in the North Sea, the Atlantic Ocean west of the Shetland Islands, and in the Celtic Sea.<sup>(12)</sup>



## OFFSHORE SUPPORT REQUIREMENTS

When petroleum exploration first moved offshore in the 1930's, the rigs were set on stationary platforms close to shore in the Gulf of Mexico. Boats were used to transport men and equipment to the rigs. As oil and gas demand increased, the exploration ventured further offshore. Now, highly sophisticated mobile rigs work in deep water out of sight of land, and water depths are being greatly extended. Offshore distances presently range up to 200 miles in some areas, and distances of 300 to 500 miles may be common in the future.

Coincident with this movement is a continuing need for improved logistics support. Helicopters have now replaced boats for many operations. Numerous factors will influence future support requirements. Some of the more pertinent characteristics of the offshore mission are discussed below.

### Drilling Technology

The modern offshore drilling fleet consists mainly of three types of rigs: the jack-up, the semi-submersible, and the drillship. The jack-up is similar to a barge and is towed to the drilling location, where it is jacked up above the sea. About half the offshore fleet is of this type.<sup>(1)</sup> From 30-60 men typically work aboard these rigs for periods of one to two weeks before being replaced. Since jack-ups are less stable in deep water, this type of rig is limited to water depths of about 300 feet. Most offshore drilling in the past has occurred in less than 300 feet of water, but the search for oil further offshore is increasing the average depth.

For greater depths and rougher weather the semi-submersible or drillship is required. Both are floating rigs with a system of anchors

to hold their position. The more stable semi-submersible is preferred in the severe conditions of the North Sea. The upper structure is clear of the sea, while a telescoping joint suspended beneath the drill floor permits drilling in heavy seas with 12 or more feet of heave. The drillship, on the other hand, can operate in very deep water, but is best in calm seas. It is used in remote locations such as Indonesia, where its capacity to store supplies allows the drillship to work at sea for months with minimum cargo support from shore.

There are from 60 to 90 men on most semi-submersibles. However, the newer, larger ones, including several of those in the North Sea, have up to 200 men. Drillships are generally in this same size range.

Most semi-submersibles and drillships are presently working in depths of less than 1000 feet of water, although some operations approach 2000 feet. The working depth of drillships is now limited by the design of the drilling riser which connects the ship to the wellhead on the sea floor. However, improved equipment design will eventually provide the freedom to work at practically any water depth.<sup>(1)</sup> This will permit greatly increased offshore distances and will alter the required characteristics of support aircraft.

#### Crew Transport

Crew changes on offshore rigs typically occur every one to two weeks, but the trend is toward more frequent rotation. Labor is beginning to demand contracts that require transportation to and from work sites at shorter intervals. Production crews are usually smaller than drilling crews, but rotate on the same weekly or biweekly basis. Industry practice for compensation of workers in transit varies widely. Some

companies pay legal minimum wages, some pay the same wages for transportation and rig time, and some use other forms of compensation.

Recent growth in the number of helicopters and boats used for offshore oil support in U. S. waters has been impressive, as Figure 7 shows. In 1973 there were 320 helicopters and 355 boats, of which 118 were crewboats. By 1975 the number of helicopters has risen to 460, a 44% increase. The number of medium helicopters, the type used in crew change operations with 8 to 14 seats, has increased by 56% in that two year span. The number of boats in 1975 is about 470, of which 129 are crew boats. It should be noted that the total number of boats grew by one-third, although the number of crewboats increased by only 9%. This indicates a shifting preference in favor of helicopters for crew change operations.

The shift from boat to helicopter as the primary means of transportation was prompted from a preference by both the men and the oil companies for the faster mode. The company incentives are the need to increase the productivity of the oil rig crews, and the fact that total trip costs with helicopters are less than those of boats for distances beyond about 50 miles.<sup>(14,15)</sup> Even at minimum wages, the cost of transporting workers 100 to 200 miles offshore by boat is excessive when time value is included. Helicopters are often used in place of boats even below 50 mile distances, due to the preference of oil rig workers for the greater speed and comfort of the aircraft.

Other forms of marine transportation, including hydrofoils, have been considered, but are not as efficient as the helicopter for moving people and equipment to and from the offshore installations. Rough

weather sometimes delays crew transfer because of inability to safely bring the boat up to the rig. In addition, several hours on a boat in rough seas often leave the crew unable to work even after reaching the rig. This is especially true of the North Sea, but also of other areas during some parts of the year. Workers transported by helicopter, however, usually arrive without delay in all but the most severe weather. Major helicopter operators serving North Sea oil and gas rigs are averaging about 98% reliability in meeting scheduled commitments.<sup>(16)</sup>

#### Emergency Operations

Besides the routine transfer of men and supplies, helicopters have proven very useful in emergency operations. Evacuation of sick or injured workers is a frequent requirement. Accident rates are high, and pain-killing drugs often are not permitted on offshore rigs. One major helicopter operator evacuates an average of one worker per night from the Gulf of Mexico,<sup>(15)</sup> although others average only a few such trips per month. Occasionally entire crews must be evacuated because of an approaching storm. In such cases, speed is of the essence.

There are also numerous requirements for emergency part delivery. Although an attempt is made to maintain critical spares on the rigs, the number of helicopter trips for unscheduled personnel and cargo transfer about equals the scheduled trips for some operators.<sup>(17)</sup> With large rigs costing as much as \$50,000 per day to operate,<sup>(18)</sup> a breakdown is very costly, making the expense of part delivery by helicopter well justified. Even with high speed boats, it would take eight or ten hours to deliver parts to the more distant locations.

Another frequent use of helicopters is to transport executive personnel to the rigs for onsite inspection. The time value of such personnel is high. Since these trips usually involve small parties, small helicopters are generally used, and the aircraft stands by for return to base.

#### Operations in the Gulf of Mexico

The first entry into the highly specialized business of oil field helicopter operation was in the Gulf of Mexico in 1949. Today there are five major helicopter operators supporting offshore operations in the Gulf with about three hundred helicopters of various sizes.<sup>(16)</sup> There are about 4000 oil and gas production platforms offshore, most of them with helicopter landing platforms.<sup>(19)</sup> On such platform is shown in Figure 8. Support bases are established all along the coast in order to reduce trip time to the various fields, and Figure 9 shows that one operator alone has 15 permanent helicopter bases between Tampa and Corpus Christi. Some of these bases could probably be eliminated if aircraft with higher speed and longer range capability were available.

While most of the helicopters used in the Gulf are small, single-engined aircraft such as the Bell 206B, there are at least 45 medium helicopters capable of carrying from 12 to 20 passengers. Service is provided to rigs as close as a few miles, and as far as 150 miles offshore. The shorter trips are generally by 3 to 4-place helicopters between rigs. Most crew changes performed by helicopter start at ranges of 40 to 50 miles, and the average trip distance for the medium helicopters is now about 105 miles. This is expected to exceed 150 miles by 1985.

There are currently more than 20,000 passenger round trips to the offshore rigs each month, plus many passenger movements between rigs. With the number of wells in the Gulf growing rapidly, and with crew sizes increasing for the large rigs drilling in deep waters, the number of workers being transported by aircraft is greatly expanding. Considering the likely increase in the average range requirement, the number of aircraft required in the late 1980's may be several times that of the present. Crew changes occur every seven days, and many companies are currently paying minimum wages for transit time. Spares and emergency service are a small part of the total helicopter operation in the Gulf, and are not considered likely to become a major part of the operation in the future. Cargo is usually not carried by helicopter, although each passenger is permitted to carry 25 lbs. of baggage.

Refueling is generally not permitted on manned rigs, so the aircraft must divert to unmanned platforms to refuel or be capable of round trip operation with normal reserves. As offshore distances increase, larger aircraft with a longer range and higher speed capability will be needed. Operators are currently taking options on the Boeing 179 and the Sikorsky S-78, civil versions of the aircraft currently in competition for the Army utility tactical transport (UTTAS) mission.

#### North Sea Operations

There are numerous differences between support operations on the Gulf Coast and those in the North Sea. The boats and helicopters used in the North Sea are generally larger, and almost all of the crew changes are accomplished with helicopters. The average trip lengths are greater, and the maximum distance a drilling rig can be located offshore is often

limited by helicopter range. Advance staging areas are often set up in remote areas 100 to 150 miles from the main base, in order to effectively extend the range of the helicopter. Spares support by helicopter is much more important in the North Sea than in the Gulf of Mexico. Even routine cargo is often carried by helicopter because weather conditions prevent offloading from boats.

Natural gas is found in the southern North Sea, where offshore distances are shorter and a high-frequency short-range helicopter service is required (more similar to that of the Gulf Coast). However, oil support operations in the rugged environment of the northern North Sea call for the largest helicopters now available. Two engines are required, not only for overwater safety, but also for the carriage of loads weighing two or three tons. Long range operations are conducted primarily with the Sikorsky S-61N or S-58T, while the smaller Bell 212 and Bolkow Bo 105 are used on the shorter routes and for small parties.

Most of the 100 or so North Sea helicopters are IFR equipped because of the poor weather conditions. However, the unpredictable and fast changing weather means that a rig landing can never be guaranteed. Therefore, payloads and distances are often reduced in favor of extra fuel to enable the helicopter to fly to and from its destination without refueling.

The average distance to the oil rigs is currently about 150 miles, although some are in excess of 200 miles.<sup>(7)</sup> As oil exploration extends further north, the average offshore distance will increase, and may exceed 250 miles by 1985. This means that distances of greater than 250 miles will be common. Some oil companies are now considering drilling

northwest of the British Isles at distances which would require aircraft with an unrefuelled range approaching 1000 miles.<sup>(11)</sup>

As offshore distances increase, aircraft capable of higher speed as well as longer range are clearly needed. The workhorse of the North Sea is now the S-61N which can carry 15 passengers about 200 miles. Nearly 50 are now in use in the area, and orders are still being placed. However, with a cruise speed of only 138 mph, it takes over three hours per round trip to some North Sea sites.



## LOGISTICS SUPPORT VEHICLES

### Boats

Boats are used in transporting men and equipment primarily in areas with calm seas. In the Gulf of Mexico, one operator uses 80, 90, or 100 ft. boats for crew change missions, and has boats up to 200 ft. for supply operations. The 100 ft. boats can be used in 95% of the Gulf weather conditions, but the 80 ft. boats are usable only in fair weather. (20)

Use of boats is even more restricted in the North Sea, since weather conditions there are among the worst in the world. During winter in the northern areas winds exceed 20 mph 60 percent of the time. In an average storm, seas of 50 to 60 ft. are encountered, with gusts of over 100 mph. (18) Fog and heavy rain often reduce surface visibility to zero. Figure 10, from reference 21, illustrates sea conditions on the day after a storm. Boats used in this environment are generally quite large, ranging to 200 ft. or more. Even so, six boats were lost by North Sea operators in 1973 due to extreme weather conditions. (21)

Typical lease costs for the Gulf Coast boats are \$650 per day (12 hours) for the 100 ft. size, and \$500 per day for an 80 ft. craft. This includes crew but not fuel or oil costs. Fuel usage is about 100 gal/hr. for the 100 ft. boat, and 60 gal/hr. for the 80 ft. boat, with a current average cost of \$0.37 per gallon. The boats are leased for an entire day, and one or more trips are made, depending upon the distance. An extra charge is made for usage over 12 hours.

About 30 passengers are carried on a typical crew change mission, although the boats are designed to carry 50 to 85 passengers. The boats may carry from 5 to 20 tons of deck cargo in addition to the passengers.

Speed of the boats ranges from 22 knots with passengers only, to about 15 knots with full cargo load.

### Helicopters

Considering currently available helicopters and those expected to be in production during the next several years, there are about 30 models to choose from. These range in size from 3 to 44 seats, and from about \$50,000 to \$6 million in price. Approximately one-half are U. S. designs.

Characteristics of medium helicopters now widely used in offshore petroleum support are shown in Table 1.<sup>(22)</sup> Table 2 lists comparable data for helicopters currently in development.<sup>(11)</sup> Normal cruising speeds of the older vehicles are in the range of 100 to 130 knots, while the newer aircraft cruise at about 150 knots. The newer helicopters also are generally larger and offer longer range.

Figure 11 illustrates range/payload characteristics for several offshore helicopters used in the North Sea. Note the requirement for a 30 minute fuel reserve, plus the need for 2 pilots and emergency equipment for overwater operation. None of these aircraft were designed for the long ranges typical of offshore operations in the North Sea, and therefore must undergo considerable payload reduction to achieve required operational capability. Range extension may be gained by addition of auxiliary fuel tanks, but this further reduces payload, as indicated by Figure 11.

The S-61N is the most popular in the North Sea because its size and range best fit the mission requirements. A disadvantage is its cruise

speed of 120 knots, which results in a round trip time of over 3 hours to some North Sea rigs. Although designed for about 30 passengers, the S-61N is operated with only about 15 to 20 seats on the North Sea, and can carry only 10 to 11 passengers to the rigs 200 n.mi. offshore. Some operators have stated a requirement for a successor which can carry a minimum of 20 passengers over 400 n.mi. at a cruise speed of at least 150 knots. (11)

Since the UTTAS derivatives (Boeing 179, S-78C) offer slightly greater maximum range capability as well as modest speed increases, one or both of these aircraft are likely to see use in the North Sea, and purchase options have been taken by operators in the Gulf of Mexico as well. With military prototypes now flying, these aircraft could be available as early as 1978. Despite the performance improvements available with these helicopters, however, the speed, range, and payload requirements of the future may not be satisfied.

The S-76 and Bell 222 are two helicopters designed largely for the offshore oil industry. That these are the first helicopters in many years developed by Sikorsky and Bell entirely with company funds and primarily for the civil market attests to the promising market potential for advanced helicopters. Along with the Aerospatiale Dauphin, these aircraft are designed to carry 10 to 12 passengers 300 to 400 n. mi. at cruise speeds of over 125 knots. The S-76 can be fitted with two auxiliary fuel tanks to increase maximum range from 400 to 600 n.mi., with a reduction in payload of four passengers. These aircraft will be more flexible and economical than present helicopters, but will still be too small for some offshore operations.

The S-65, a civil version of the CH-53, offers the greatest range and payload of any civil helicopter in the planning stage. Designed to carry 44 passengers 260 n.mi. at 150 knots, the S-65 can also carry 30 passengers 600 n.mi. However, development will not proceed without at least 20 firm orders.<sup>(11)</sup> Two disadvantages are its price, which is about \$6 million, and its gross weight, which at 35,000 lb. may exceed the structural limits of some offshore platforms.

#### Advanced VTOL Aircraft

With offshore distances increasing rapidly, means of extending the range of support aircraft are required. At the same time, it is clear that simply increasing engine size and adding fuel tanks provides only a partial solution. Range can be improved, but speed is only slightly increased, and unit operating costs increase as aircraft productivity is reduced by offloading passengers.

A more satisfactory solution to future requirements may be the development of advanced VTOL aircraft with greatly improved cruise efficiency. This would permit significant range increases due to better fuel utilization efficiency, and would also provide increased aircraft productivity through cruise speed increases. Potential benefits to the petroleum industry include increased rig crew productivity (less time in transit), better emergency evacuation capability, and faster parts delivery. Benefits to the aircraft operator include lower operating costs and lower capital investment. The operating costs would be less since higher aircraft productivity reduces per-mile charges for depreciation, insurance, and pilot pay, and since fuel expenses would be reduced. Perhaps land base expenses could also be reduced if the number of

support locations were reduced. The aircraft fleet capital investment would be less if the cruise speed increment permits a reduction in fleet size proportionately greater than the price difference between the advanced aircraft and the helicopter it is replacing.

Three promising advanced VTOL concepts are the lift/cruise fan, the tilt rotor, and the compound helicopter. These aircraft are very different in appearance and performance, and in many ways represent a significant departure from current helicopters used in offshore petroleum support.

Figure 12 illustrates representative designs of the three concepts. The compound helicopter differs from conventional helicopters in having a wing and auxiliary propulsion system for cruise. The tilt rotor, on the other hand, uses the same propulsion system for vertical operation and cruise. With rotors mounted on the wing tips, the aircraft takes off and lands like a helicopter, but the rotors may be rotated 90° forward for cruise like a turboprop. The lift/cruise fan aircraft dispenses with rotors entirely by employing large fans and vectoring nozzles mounted on the wing and in the fuselage for vertical takeoff and landing. The fuselage lift fan is shut down for cruise flight, where the wing lift/cruise fans are utilized as efficient high bypass engines.

Each of these concepts offers potential advantages to the offshore industry. While the conventional helicopter is the most efficient in hover, this is a relatively small part of the typical offshore mission. High cruise efficiency is very important to long range capability, and cruise speed is crucial to the economic productivity of the aircraft.

Table 3 compares the estimated performance characteristics of representative designs for these three VTOL concepts to those of a future conventional helicopter. The data for all four aircraft were taken from conceptual design studies conducted for military V/STOL missions, and are not necessarily representative of designs optimized for offshore oil application. The performance capabilities of these aircraft are greater than that required for most current offshore operations. However, the more demanding operations of the future will likely require aircraft with all-weather capability and improved passenger comfort in addition to increased range, payload, and speed. The availability of data from the military aircraft studies thus permits a preliminary analysis of the benefits of advanced VTOL aircraft in future operations.

The three rotorcraft were sized for a mission involving several hours in loiter and hover plus a 300 n.mi. cruise. The available fuel capacity, in combination with good cruise efficiency, therefore provides range capability much greater than that of any helicopter now in use. The cabin size is sufficient for 23 passengers plus a crew of three, although three crew members are not required to operate the aircraft. Performance estimates for the offshore oil mission indicate unrefuelled operation with 23 passengers to rigs at the round trip distances shown in Table 3.<sup>(23)</sup> More distant operations would require payload reductions in exchange for additional fuel.

The lift/cruise fan aircraft was sized for a transport mission of 2000 n.mi. with a 5600 lb. payload including STO takeoff and vertical

landing. Maximum gross weight is 44,800 lb. for STOL operation and 34,500 for VTOL. With vertical takeoff the fuel load is reduced by nearly 60%, which decreases the range to about 700 n.mi. for full payload. Since most offshore petroleum operations could include STO takeoff at the land base combined with VTOL operation at the offshore rig, the unrefuelled range is about 1300 n.m. with 23 passengers.

The three rotorcraft designs were developed by the same contractor, and all represent similar advances in component state of the art.<sup>(24)</sup> That is, all employ hingeless rotors with composite blades, conventional metal structure in primary airframe components, moderate use of composites in secondary structure, and fly-by-wire control systems. The lift/cruise fan data are from a design study by a different contractor,<sup>(25)</sup> but represent generally similar component technology levels except that the engine technology is less advanced.

The conventional helicopter is the simplest, lightest, and least expensive of the four concepts. However, it is also the slowest and least productive, and offers the lowest growth capability.

The compound helicopter provides greater speeds than the conventional helicopter but incurs a weight and cost penalty due to the wing and auxiliary propulsion system. The productivity increase is offset by the higher aircraft price, resulting in a higher unit operating cost. The concept was eliminated from further consideration for the offshore mission.

Figure 13 compares the unrefuelled range-payload performance of the lift/cruise fan and tilt rotor to that of the advanced helicopter. The

aircraft direct operating costs versus radius are shown in Figure 14. The overall productivity of the two faster aircraft is much greater than that of the helicopter, and per-mile operating costs are less than those of the helicopter despite the higher hourly costs.

Both the tilt rotor and lift/cruise fan aircraft offer superior economics for operations more than 50 to 75 n.mi. offshore, and the lift/cruise fan appears most economical beyond about 250 n.mi.

There are numerous factors which could alter the indicated cross-over points, so caution must be exercised in drawing conclusions from an analysis of this type. For example, differences in the weight and cost estimating methodology used by the two contractors could easily change the estimated price of either aircraft by 20% or so. This would directly impact depreciation and insurance charges, which represent about 30% of the DOC.

Confidence in the cost and performance estimates of the helicopter is greatest since it is the only one of the three concepts for which operational vehicles have been built. Aircraft development costs and maintenance manhours per flight hour are less certain for the other designs, although an attempt was made to realistically account for the economic penalties associated with the greater complexity of the tilt rotor and lift/cruise fan.

The range growth capability of the tilt rotor is the greatest of any of the four concepts due to its very low fuel consumption in cruise. The importance of this long range capability may be greater than is at first apparent. With a radius of operation roughly twice that of



helicopters, a tilt rotor could support petroleum exploration much further offshore, and could possibly contribute to a greatly expanded availability of energy in the 1990's. In the North Sea especially, drilling plans are now limited by the range capability of available helicopters.<sup>(11)</sup>

A potential disadvantage of the tilt rotor is the existence of large rotors at the wingtips. The total tip-to-tip width with rotors turning is 85 ft. for the 23 passenger model compared to rotor diameters of 62 feet for the S-61N and 72 ft. for the S-65. This may cause a landing clearance problem on some drilling rigs, but would probably not pose a problem on the larger rigs or on production platforms, which usually have no superstructure. Presumably this problem could be resolved by modifications to the landing platform if the advantages of the tilt rotor are sufficient.

The lift/cruise fan offers a significant advantage in speed capability over any of the other VTOL concepts. With high wing loading and normal cruise at about M 0.75 it offers passenger comfort and trip times approaching those of conventional jet transports. The aircraft weight and purchase price is greatest of any of the concepts, and fuel utilization efficiency is between that of the tilt rotor and helicopter.

Figure 15 compares the direct operating cost of the S-61N, with and without offshore refuelling, to that of a future tilt rotor or lift/cruise fan, based on similar assumptions for fuel price, maintenance labor rates, etc. Due to uncertainties in the ultimate price and maintenance requirements of the yet undeveloped advanced VTOL aircraft, a sensitivity analysis was run to determine the impact of a 50% increase in both

aircraft purchase price and maintenance manhours per flight hour. The result is the DOC band shown in Figure 15. Whereas the DOC of the S-61N increases with range due to the offloading of passengers, the advanced aircraft economics would continue to improve with distance out to its design range. This figure suggests that advanced VTOL aircraft would be superior for offshore distances over 100 n.mi. regardless of the concept selected or the accuracy of the present cost projections.

The productivity of the S-61N and the advanced aircraft are compared in Figure 16. The higher speed aircraft perform more missions per day, and hence could transport more passengers. This productivity advantage is enhanced as range increases, since the S-61N must trade payload for fuel. The faster aircraft would permit a significant reduction in the number of pilots and in the required investment in aircraft, spares, and ground support equipment. The higher productivity would also be important in the evacuation of large numbers of oilmen prior to major offshore storms, an occasional requirement.

## BENEFITS OF ADVANCED VTOL AIRCRAFT

In a study of the potential application of advanced aircraft to the offshore mission, several factors must be considered. These are: 1) the capital required to provide the new VTOL aircraft; 2) the productivity and operating costs of the new aircraft compared to existing helicopters; and, 3) benefits to the petroleum industry resulting from the special characteristics of the aircraft, such as improved range, speed, or payload capability.

The Gulf of Mexico and the North Sea were selected for this analysis because extensive use of helicopters in these areas provide a data base with which to make realistic comparisons. There is much uncertainty regarding the payload size and range for which concepts such as the tilt rotor and lift/cruise fan could effectively compete with advanced helicopters. However, it appears that such aircraft would offer the most advantage in crew change and cargo movement operations, where the higher aircraft weight and price can be offset by higher productivity. Small helicopters used for short hops and for transportation of executives and specialists are less likely to be replaced by other aircraft concepts. There will, of course, be a strong market for advanced helicopters which offer greater speed and operating economy than the hundreds of small helicopters now used in offshore operations.

### Gulf of Mexico

More than 4000 oilmen are moved by helicopter every day in the Gulf of Mexico. The total cost of running the fleet of 300 helicopters is estimated to be at least \$40 million per year, based on an analysis of

the expenses of two of the largest operators. Advanced helicopters and VTOL aircraft can provide DOC reductions of as much as 30% to 50% at the current 75 to 130 n.mi. offshore distance typical of Gulf operations. This indicates a potential annual savings of \$12 to 20 million, at the present rate of offshore activity, with replacement of the entire fleet. Of course, such replacement would be gradual even if the advanced aircraft were available now.

The savings to the aircraft operator is due to the increased aircraft productivity. There are additional benefits of high speed aircraft which would accrue directly to the petroleum industry. Reduced travel time would increase the productivity of the oilmen. This time value may be only \$2.60 per hour for those companies paying minimum wages to crews in transit, but would be much higher for those paying full wages. In addition, managers or specialists making on-site inspections would generally be traveling during normal working hours and thus at a high time value.

A complete measure of the total benefits of high speed aircraft would include spares support and emergency operations since a lower down time yields a higher rig productivity. Although it is a consideration in the current use of helicopters, there was not sufficient data to include this in the present benefits analysis. Only the savings due to aircraft operating costs and oil worker productivity were included.

The ten year benefits due to the introduction of advanced VTOL aircraft in 1985 are compared in Table 4. The benefits in this table reflect only the medium helicopter market. Savings in aircraft expenses and oilmen salaries due to introduction of new small helicopters are not included.

It was assumed that the average offshore distance of rigs served by the larger aircraft will increase to 130 n.mi. in the decade after 1985. This appears to be a very conservative estimate in light of current trends. It was also assumed that the number of passenger round trips for crew change operations would increase from about 22,000 per month now to an average of 60,000 per month in the 1985 to 1995 time period. This represents a 7% average annual increase, considerably below recent growth rates in offshore activity.

The estimated number of aircraft required reflects a 100 hour per month average utilization and an average of 15 passengers per trip, which is a 65% load factor for the 23 seat aircraft. In contrast, only 10 passengers can be carried this distance by the S-61N (without refueling). The required capital investment for aircraft and spares (25% of aircraft price) is listed for comparison, and it should be noted that the high speed aircraft provide a 30% to 50% reduction despite a higher unit price. These values were not added to the ten-year benefits since the aircraft DOC already includes a depreciation term which amortizes the investment.

The oil worker productivity gain in Table 4 is the total ten-year wage savings realized by transporting crews to and from the offshore rigs once per week with advanced aircraft instead of current helicopters. The transit time value of each worker was assumed to be \$2.60 per hour. Not included in the table is another \$30 million or so which could be saved over a ten year period by transporting high-time-value personnel during normal working hours on small advanced helicopters.

The total indicated benefit over a ten year period for converting to the advanced aircraft is significant, ranging from \$514 million for 180 knot helicopters to \$661 million for the lift/cruise fan. The tilt rotor and lift/cruise fan provide nearly equal benefits at this offshore distance. No attempt was made to estimate the benefits of a mixed fleet, although a realistic assessment would indicate that some of each aircraft type are probably desirable for operational flexibility.

Neither the tilt rotor nor the lift/cruise fan are operational aircraft concepts, and much technology development is necessary to permit realization of the indicated benefits. Although the acceptability of a concept to the user community cannot be predicted with certainty, a simple comparison can be made of the investment value of each aircraft type to evaluate the likelihood of it being used if available. The savings in aircraft operating cost become pre-tax profits to the aircraft operator assuming constant revenue for passengers hauled. The ability of the advanced aircraft to generate increased operating profits with a reduced capital investment indicates that these concepts would be very attractive to the aircraft operators.

The growth rate in offshore transportation requirements is very uncertain. This is true for several reasons: (1) the future pace of offshore petroleum activity is uncertain due to economic and political considerations; (2) frequency of crew rotation may change; (3) developments in petroleum production and drilling technology may alter the number of men required to operate the rigs. The average offshore distance is also uncertain due to unknowns in future drilling technology, and because the exploration cost increases greatly in deeper water.

For all of these reasons, the annual benefits for each aircraft type were computed as a function of both average distance and passenger demand. The result is shown in Figure 17. The band for each offshore distance represents the range of benefits from the advanced helicopter (lower line) to the tilt rotor and lift/cruise fan (upper line). The width of the band is the potential benefit of the lift/cruise fan or the tilt rotor in a comparison with advanced helicopters. The benefits shown are relative to the Bell 212 at 90 n.m. and relative to the S-61N at 130 n.m. and 220 n.m. This is because the Bell 212 is more economical at the shorter range, but the S-61N would most likely be required for the greater distances. Note that even with very modest growth in transportation requirements the advanced aircraft would provide significant annual benefits to the industry.

#### North Sea

Nearly one-half of the estimated 100 helicopters currently operating in the North Sea are S-61N's, with an operating cost of about \$560 per hour. Since the other 50 helicopters are smaller, the average cost for the entire fleet may be about \$400 per flight hour. At an average utilization of 80 to 100 hours per month the annual cost of providing helicopter service to the offshore rigs is estimated to be \$40 or \$50 million.

Figure 16 indicates that advanced VTOL aircraft could reduce the expense of operations to the more distant rigs (about 200 n.mi. offshore) by either 60% or 30%, depending upon the weather. If a rig landing can not be guaranteed, the S-61N passenger complement must be reduced to 10, with a very high cost per passenger-mile. If, however, good flying

conditions and fuel availability on the rig assure that the S-61N can be refueled for the return flight, 17 passengers can be carried and the cost per passenger-mile drops from 52¢ to 32¢. Even so, the advanced VTOL would have a large economic advantage at 17¢ per passenger-mile. This suggests that total savings achieved by replacing the current S-61N fleet alone could reach \$10 to \$15 million per year.

Table 5 compares the estimated benefits of the advanced aircraft to the S-61N for 1990 operations in the North Sea. Note that the average offshore distance projected for 1990 is greater than that in the Gulf of Mexico, as it is now. The assumed passenger demand is also greater than in the Gulf for two reasons. First, North Sea oil exploration is at a much earlier stage of development, and thus can be expected to show a greater rate of growth. In addition, many North Sea workers now remain on the rigs for two weeks at a time, but crew rotation is expected to occur weekly by 1985.<sup>(12)</sup> Assuming a net growth of 11% per year yields a total passenger demand of 75,000 round trips per month in 1990, compared to an estimated 12,500 in 1973.

The combination of the high traffic level and the greater offshore distance leads to a potential savings of about \$2 billion for the ten year period with replacement of S-61N helicopters by advanced VTOL aircraft. Although the S-61N is the most popular North Sea helicopter today, it is unlikely that it would be used for the range indicated because of its performance limitations. A more realistic comparison would be against improved helicopters such as the UTTAS derivatives, which are expected to be available about 1978. In this case, the indicated benefits would be much less, as Table 6 shows.



The UTTAS derivatives appear well suited for many North Sea operations with ranges of 350 to 400 n.m. at a payload of 20 or more passengers. Auxiliary fuel tanks are required for unrefueled operation to rigs more than 200 n.m. offshore, however, and the advantages of the advanced aircraft would increase for the more distant rigs. The indicated benefits in Table 6 are conservative, as the UTTAS is near maximum payload for that radius, while the advanced aircraft are being operated at a 65% load factor.

## CONCLUSIONS

The worldwide need for energy is creating a tremendous expansion in offshore petroleum activity despite the high costs involved. As improved drilling technology permits recovery of oil and gas from deeper waters the offshore distances will continue to increase. This will complicate the logistics support required to maintain the flow of men and materials to the rigs, and will greatly increase the number of vehicles needed.

Marine vessels provide a variety of support functions, including towing, pipeline laying, cargo supply, and personnel transportation. The use of helicopters is growing rapidly for personnel movements because of superior speed and comfort. The fast response of helicopters in emergencies is also important to safety and to maintaining high rig productivity. With the ability to reach rigs 200 miles offshore in about 1.5 hours, the helicopter economics and general suitability for many operations are superior to those of boats, which would take more than 10 hours. This advantage is enhanced in rough weather such as that of the North Sea, where operation of boats is difficult.

As offshore distances increase, the size of the rig crew tends to increase, both because of increased rig sophistication and because it becomes economical to keep more specialists aboard. The trend in helicopter purchases is toward larger aircraft in order to provide the increased range and payload capability required. Greater speed is also sought as a means of further increasing the aircraft productivity.

Current helicopters provide relatively poor cruise efficiency, which limits maximum speed and range. The passenger load must be severely

reduced to provide sufficient fuel to reach the more distant rigs. This greatly increases the unit operating cost and the number of aircraft required.

Offshore refueling stations would extend the range capability of helicopters, but this would further increase trip time and operating costs. Many operators do not permit offshore refueling on manned rigs for safety reasons.

A need clearly exists for advanced helicopters with greater cruise efficiency. Helicopters now in development will provide better range/payload capability as well as 20% to 30% increases in cruise speed. This will provide significant improvements in operating economics. Further gains are possible through advanced helicopter technology now in progress.

Future petroleum activity 200 to 500 miles offshore will require even greater improvements in VTOL aircraft efficiency. Concepts such as the tilt rotor and lift/cruise fan are very promising. Due to good fuel utilization efficiency, greatly extended range of operation is possible without refueling. The cruise speed of these concepts is also greater than that of either current or advanced helicopters. The tilt rotor provides nearly twice the range of the helicopter for the same fuel and trip time. The lift/cruise fan cruises at three times the speed of the helicopter and also yields a greater range/payload capability.

The greater productivity of the lift/cruise fan and tilt rotor would permit reductions in fleet size, with lower capital investment in aircraft, spares, ground equipment, and pilot training. Aircraft direct operating costs may be significantly less than those of current helicopters

at offshore distances above 50 to 100 miles. The faster aircraft would provide several other advantages, including better emergency evacuation capability, faster parts delivery in times of unexpected rig shutdown, and increased crew productivity through reductions of time in transit.

Despite a higher purchase price the per-mile costs of the high speed aircraft would be very attractive, even in a comparison with advanced helicopters, at the ranges likely in future offshore operations. However, uncertainties in future offshore requirements and in the ultimate values of aircraft price and maintenance cost for concepts still in the technology development phase preclude a selection of any one preferred concept at this time.

Each VTOL aircraft type has a role to fill in future offshore logistics operations, as does the boat. Tilt rotors or lift/cruise fan aircraft cannot economically replace helicopters in the short-range operations. There will be a continuing need for advanced helicopters for movement of small parties of executive and specialist personnel during on-site inspections, and for crew change operations on the many rigs close to shore. The more distant operations will best be performed with either the tilt rotor or lift/cruise fan, or possibly with improved compound helicopters. The ideal fleet would consist of some mix of the different aircraft concepts.

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TABLE 1

## COMPARATIVE DATA FOR MEDIUM HELICOPTERS

	SIKORSKY S-61N	SIKORSKY S-58T	AEROSPATIALE PUMA	BELL 212	BELL 205A	BOEING 107
No. Engines	2	1	2	1	1	2
Gross Weight (lb)	19,000	13,000	14,800	11,200	9500	19,000
Useful Load (lb)	6664	5600	6965	5527	4542	7433
Max Fuel (lb)	2747	1896	2747	1440	1474	2345
Max Seats	26-31	16	20	13	14	29
Normal Cruise Speed (kt)	120	110	130	105	96	128
Range (n.mi.)	300	250	318	239	275	250
Approximate Price (\$M)	2.37	0.6	1.3	0.7	0.5	2.1

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TABLE 2  
COMPARATIVE DATA FOR MEDIUM HELICOPTERS IN DEVELOPMENT

	<u>BOEING</u> <u>179</u>		<u>S-78C</u>		<u>S-65</u>		<u>S-76</u>		<u>BELL 222</u>		<u>AEROSPATIALE</u> <u>DAUPHIN</u>	
No. Engines	2		2		2		2		2		2	
Gross Weight (lb)	18,700		20,000		35,000		9585		6700		6600	
Max Fuel (lb)	3215		3050		4180		1800		715		1170	
Max Seats	25		20		44		12		10		12	
Normal Cruise Speed (kt)	140		146		152		125		130		125	
Max Cruise Speed (kt)	158		168		163		155		156		135	
Range @ Max Payload (n.mi.)	400		400		260		400		370		300	



TABLE 3

## ADVANCED VTOL AIRCRAFT DATA

	<u>LIFT/CRUISE FAN (MCDONNELL)</u>	<u>TILT ROTOR (VERTOL)</u>	<u>COMPOUND HELICOPTER (VERTOL)</u>	<u>ADVANCED HELICOPTER (VERTOL)</u>
Gross Weight (lb)	34,500	31,789	30,814	29,944
Operating Empty Wt.	21,156	17,822	16,504	15,042
Max Fuel (lb)	7744	8367	8710	9302
Max Seats	23	23	23	23
Design Cruise Speed (kt)	490	300	225	180
Range With 23 Pass. (n.mi.)	700 (1300 ST0)	2000	-	750
Estimated Price (\$M)	3.67	2.83	2.95	2.51
Op. Cost (\$/ft. hr.)	950	700	715	590

TABLE 4  
TEN-YEAR BENEFITS OF ADVANCED VTOL AIRCRAFT  
TO OFFSHORE PETROLEUM OPERATION IN GULF OF MEXICO  
(130 n.mi. offshore; 60,000 passenger round trips per month)

	<u>S-61N</u>	<u>Advanced Helicopter</u>	<u>Tilt Rotor</u>	<u>Lift/Cruise Fan</u>
Cruise Speed (kt)	110	160	270	450
Round Trip Time (hours)	2.75	2.08	1.45	1.05
Passengers Per Aircraft	10	15	15	15
No Aircraft	165	83	58	42
Capital Investment (\$M, incl. spares)	393	260	206	193
Ten-Year Worker Productivity Gain (\$M)	-	12	24	31
Aircraft Operating Cost (\$M/mo.)	9.24	5.06	4.06	3.99
Ten-Year A/C Oper. Savings (\$M)	-	502	622	630
Total Ten-Year Benefit (\$M)	-	514	646	661

TABLE 5  
TEN-YEAR BENEFITS OF ADVANCED VTOL AIRCRAFT  
TO OFFSHORE PETROLEUM OPERATION IN NORTH SEA  
(220 n.m. offshore; 75,000 Passenger Round Trips per Mon.h)

	<u>S-61N</u>	<u>Advanced Helicopter</u>	<u>Tilt Rotor</u>	<u>Lift/Cruise Fan</u>
Cruise Speed (kt)	110	180	300	490
Round Trip Time (hours)	4.65	3.1	2.2	1.6
Passengers Per Aircraft	8	15	15	15
No Aircraft	431	155	110	80
Capital Investment (\$M, incl. spares)	1024	484	389	367
Ten-Year Worker Productivity Gain (\$M)	-	36	56	71
Aircraft Operating Cost (\$M/mo.)	24.1	9.2	7.7	7.6
Ten-Year A/C Oper. Savings (\$M)	-	1,788	1,968	1,980
Total Ten-Year Benefit (\$M)	-	1,824	2,024	2,051

TABLE 6

TEN-YEAR BENEFITS OF ADVANCED VTOL AIRCRAFT  
TO OFFSHORE PETROLEUM OPERATION IN NORTH SEA  
(220 n.m. offshore; 75,000 Passenger Round Trips per Month)

	UTTAS Derivative	Advanced Helicopter	Tilt Rotor	Lift/Cruise Fan
Cruise Speed (kt)	140	180	300	490
Round Trip Time (hours)	3.9	3.1	2.2	1.6
Passengers Per Aircraft	15	15	15	15
No Aircraft	195	155	110	80
Capital Investment (\$M incl. spares)	426	484	389	367
Ten-Year Worker Productivity Gain (\$M)	-	18	38	53
Aircraft Operating Cost (\$M/mo.)	9.3	9.2	7.7	7.6
Ten-Year A/C Oper. Savings (\$M)	-	12	192	204
Total Ten-Year Benefit (\$M)	-	30	230	257

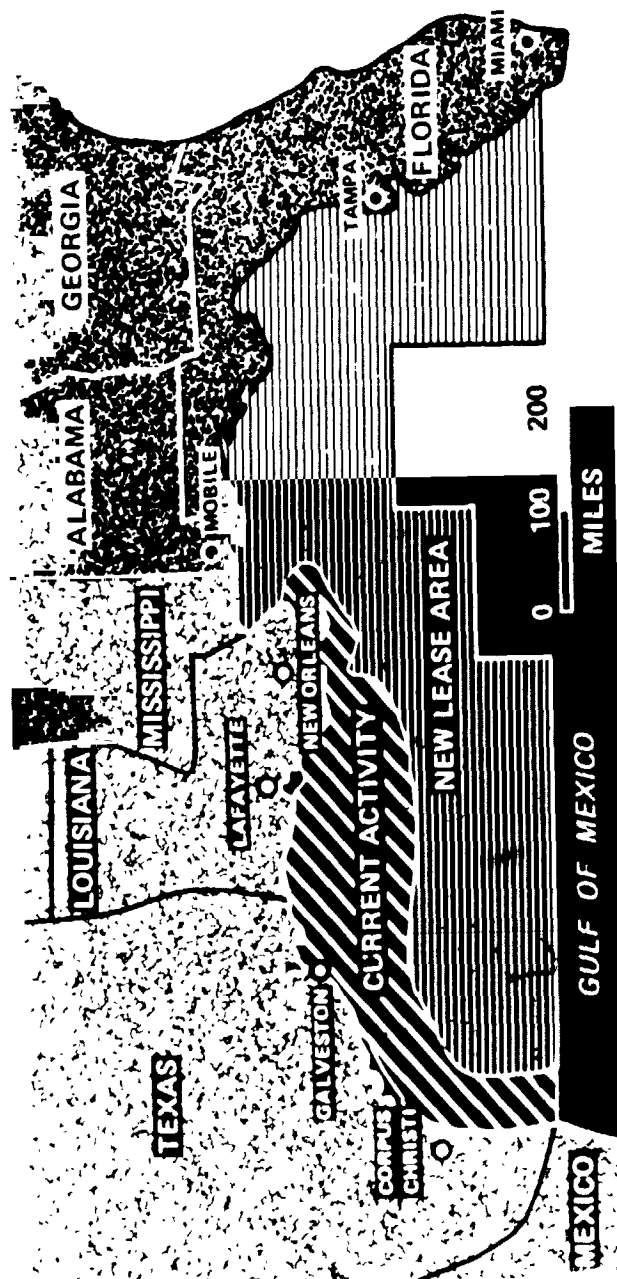


Figure 1.- Offshore petroleum activity in the Gulf of Mexico.

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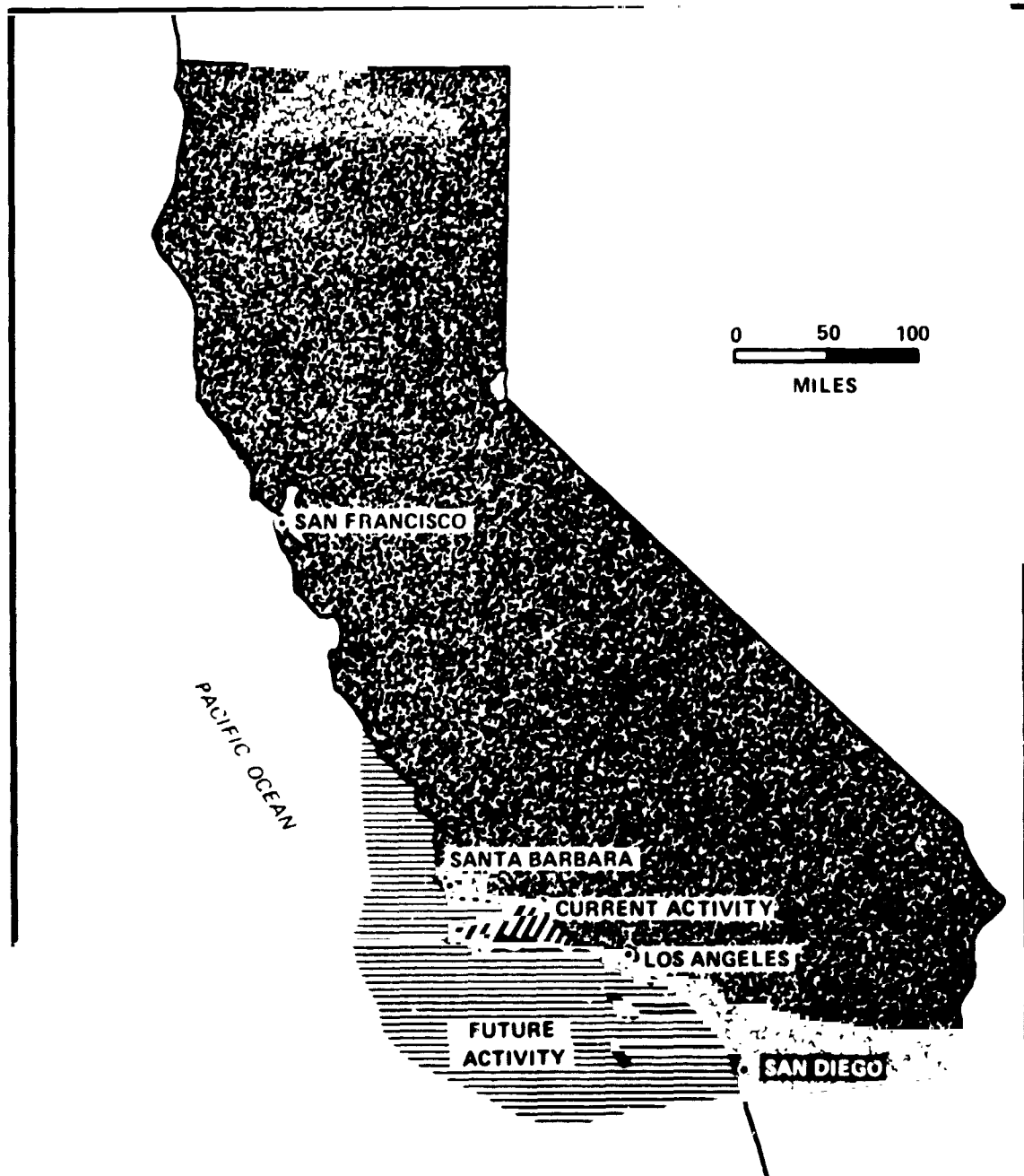


Figure 2.- Offshore petroleum activity off the U. S. Pacific Coast.

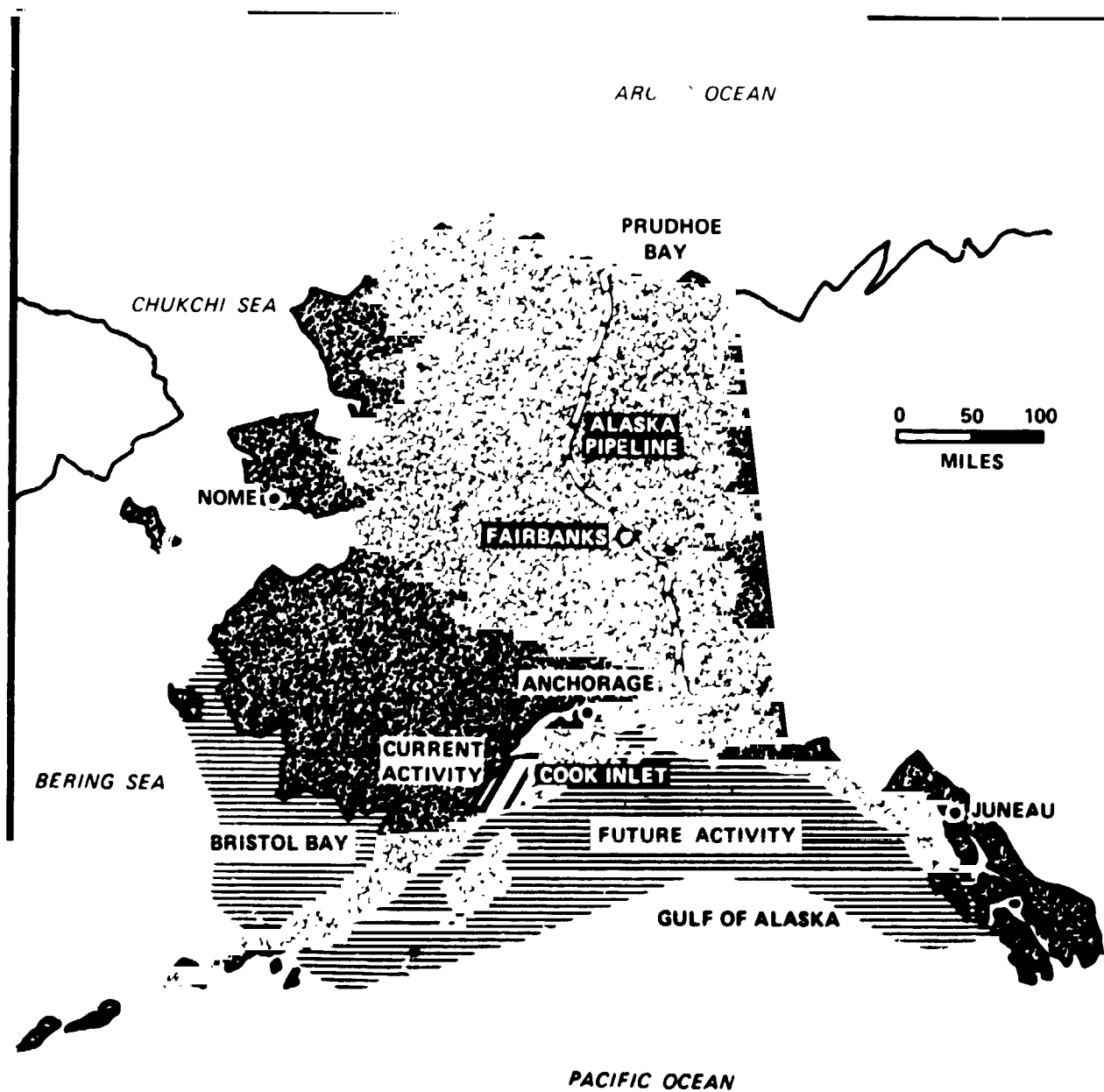


Figure 3.- Offshore petroleum activity along the Southern Alaska Coast.

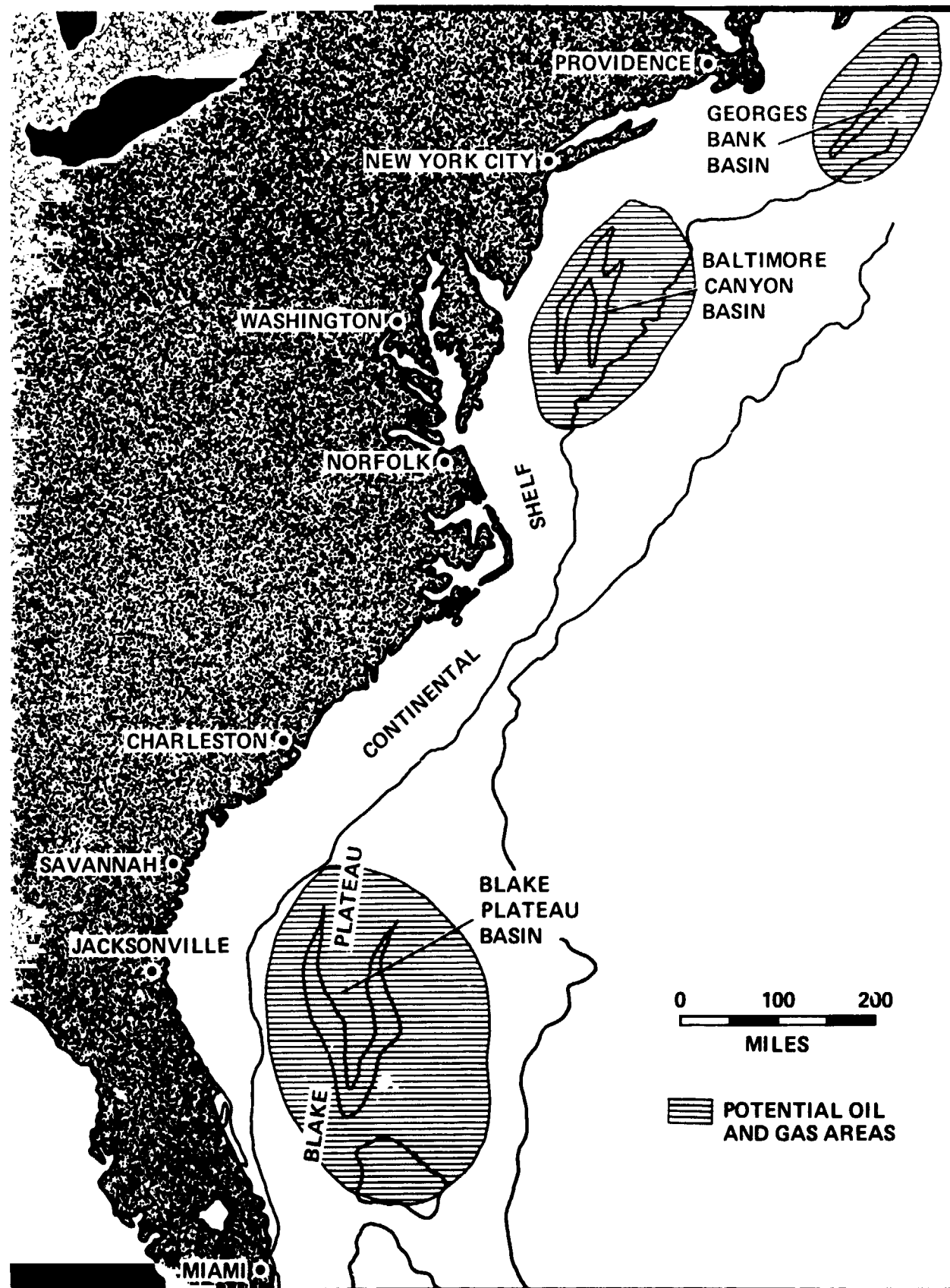


Figure 4.- Potential oil and gas sites along the U. S. Atlantic Coast.



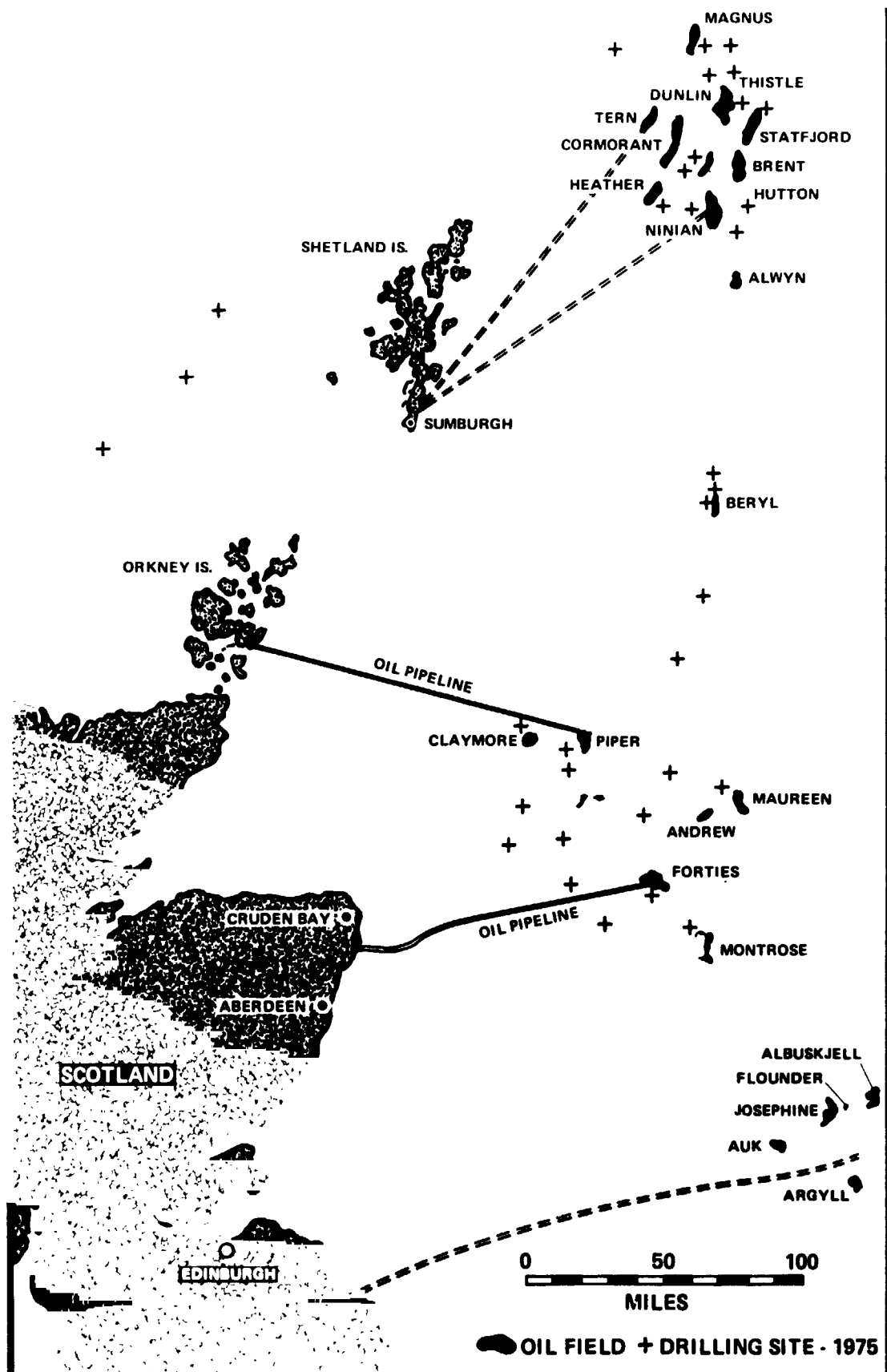


Figure 5.- North Sea petroleum sites served by British helicopters.

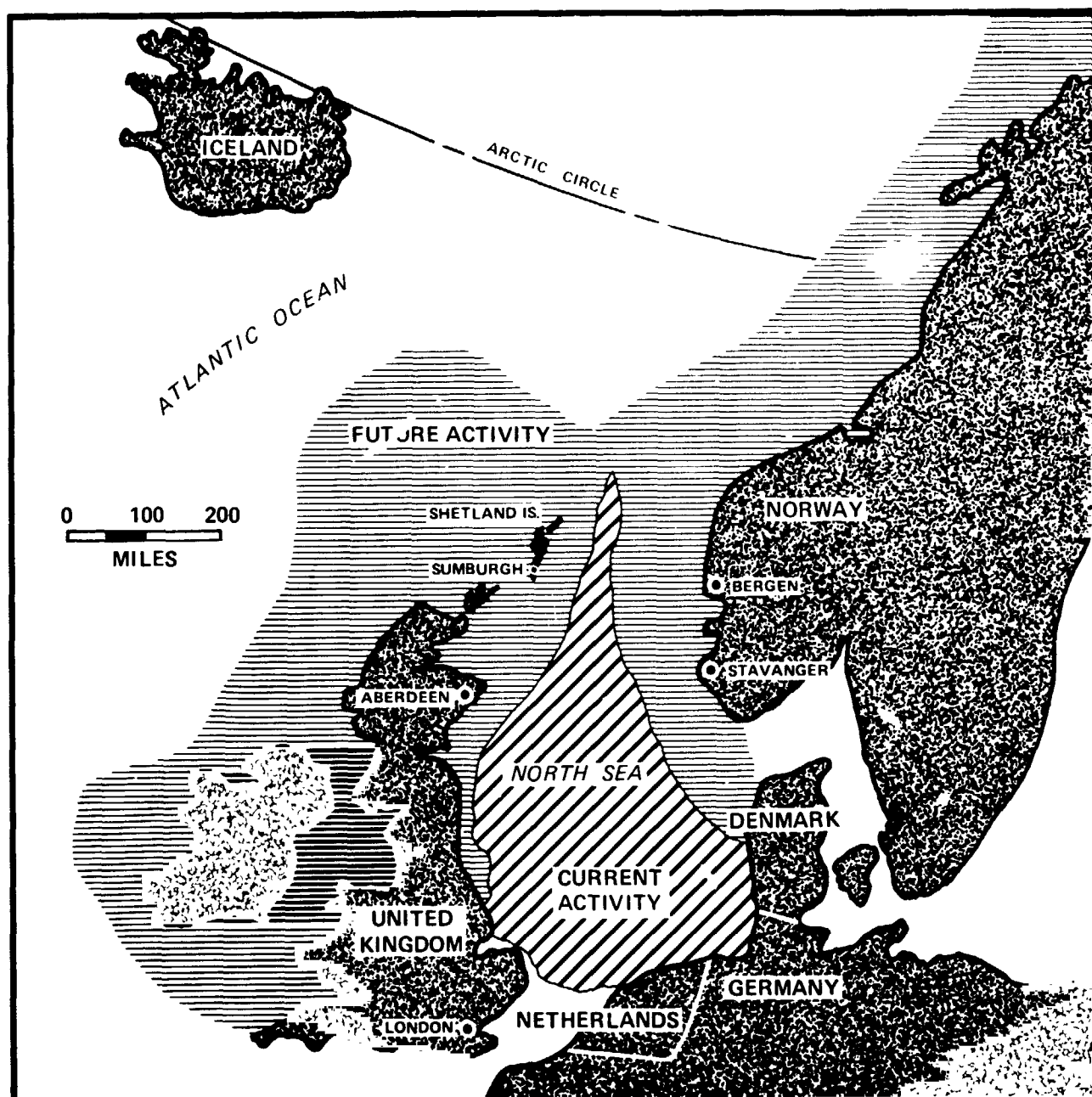


Figure 6.- Offshore petroleum activity in the North Sea.

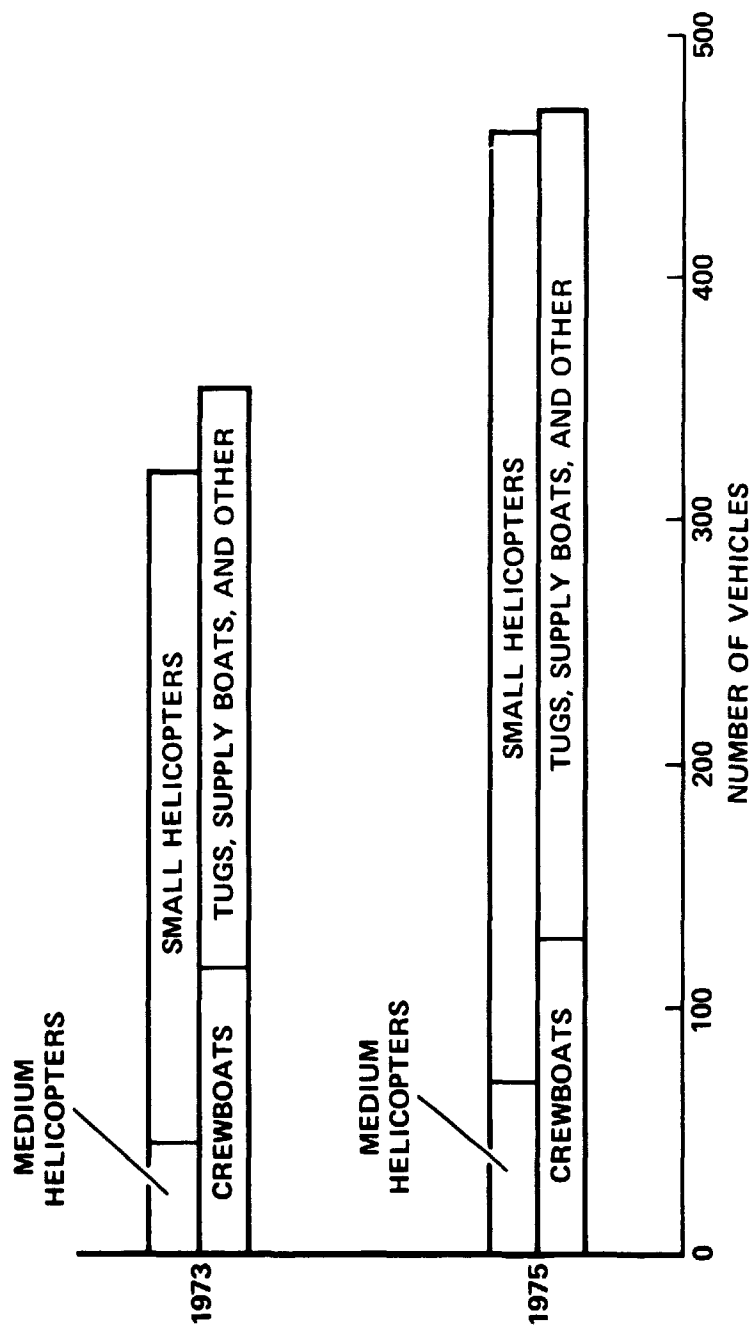


Figure 7.- Growth in offshore logistics vehicles - U. S. waters.

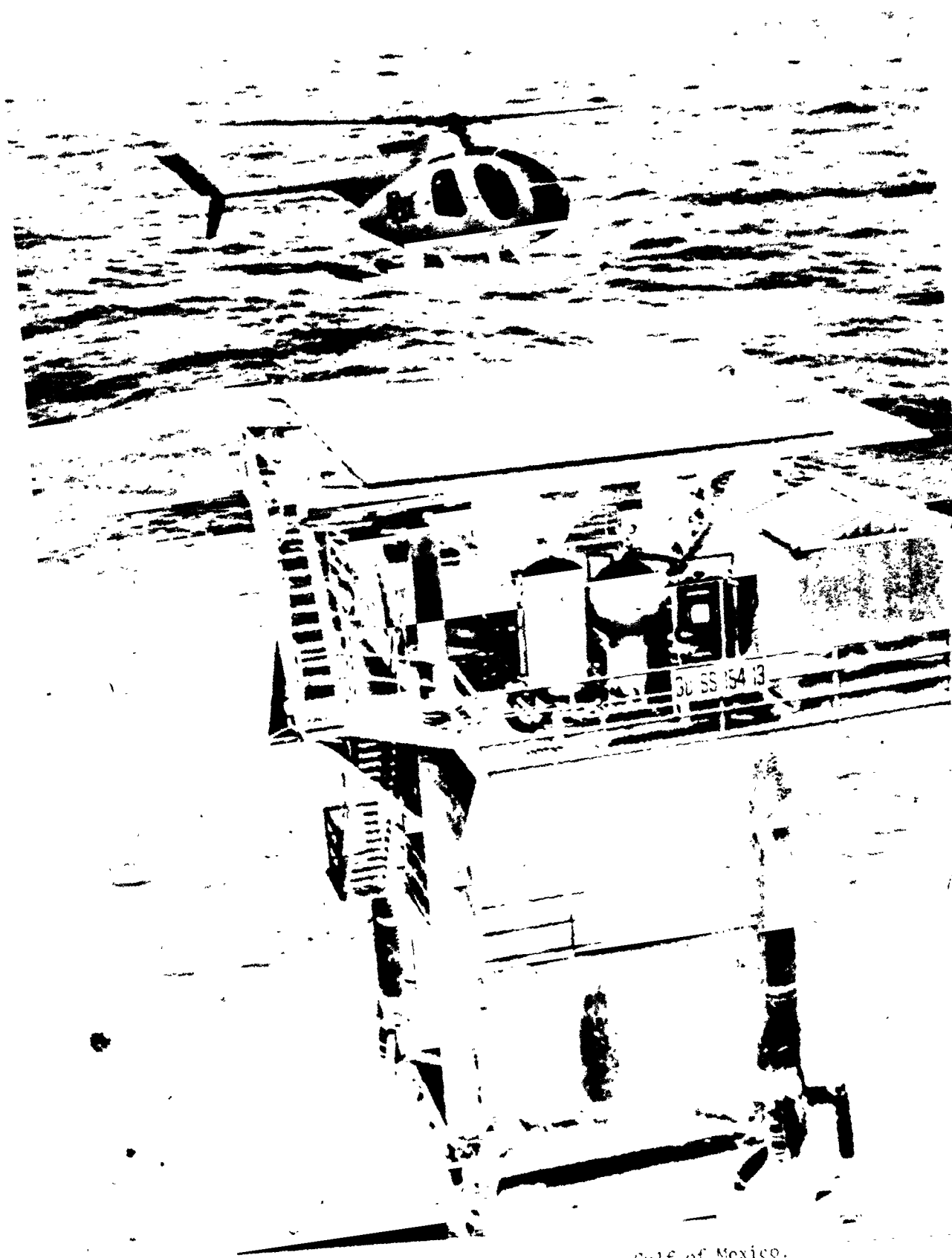


Figure 8.- Production platform in Gulf of Mexico.

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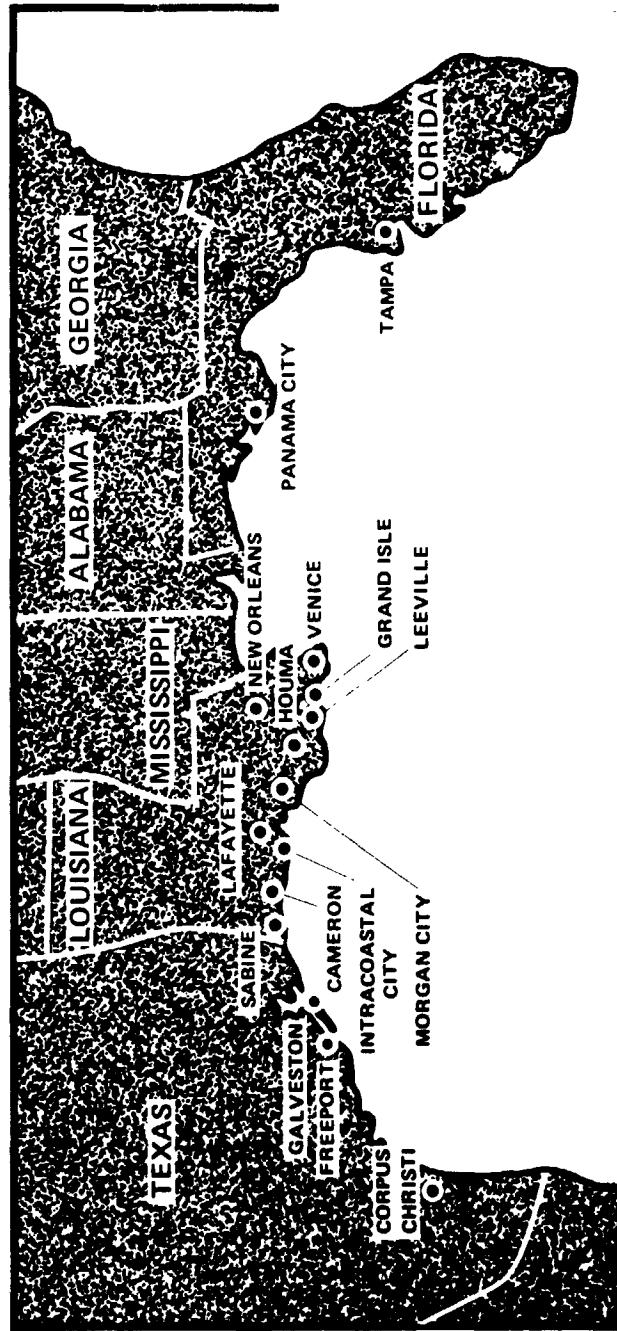


Figure 9.- Helicopter bases used by one Gulf Coast operator.



Figure 10.- Building view in the North Sea.

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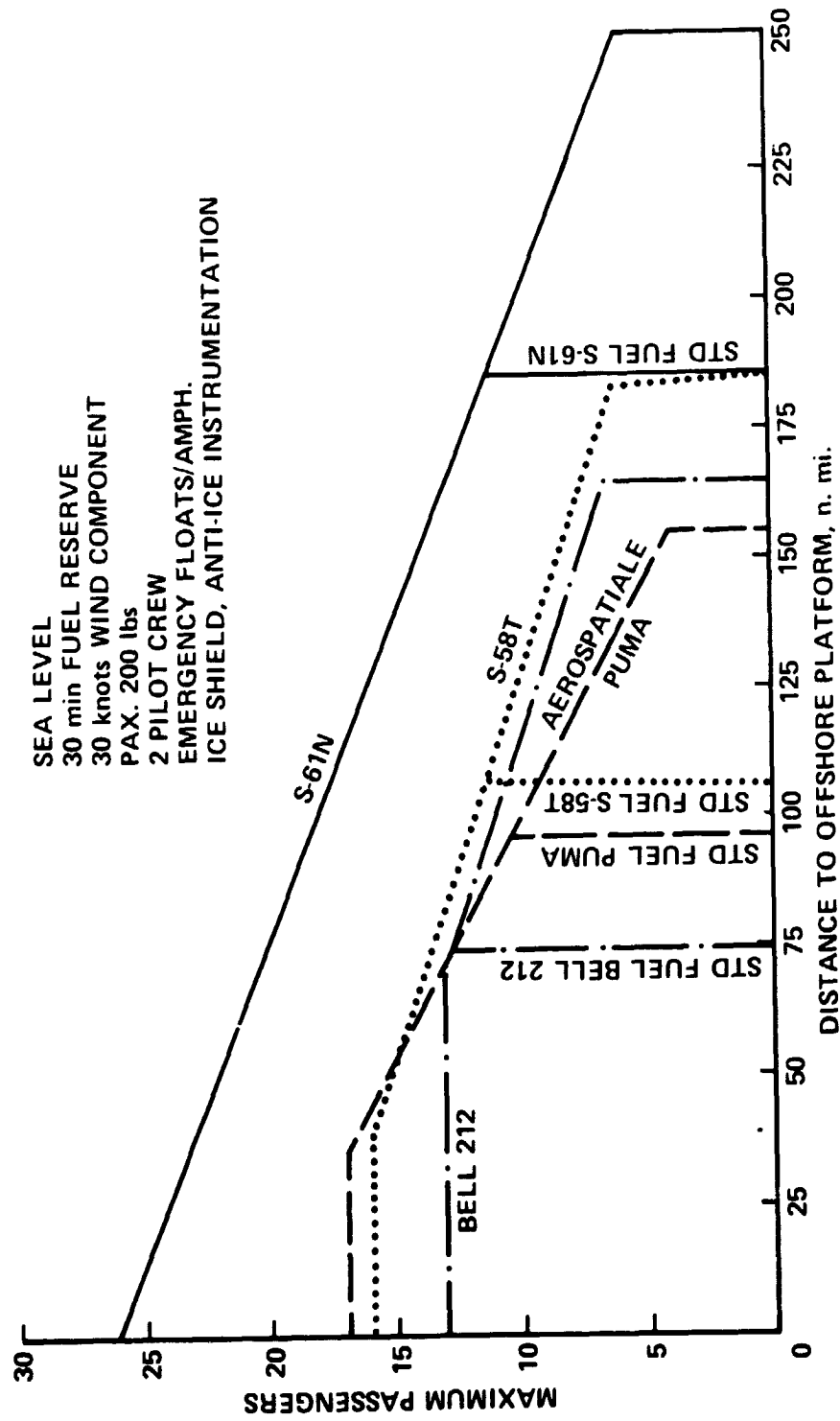
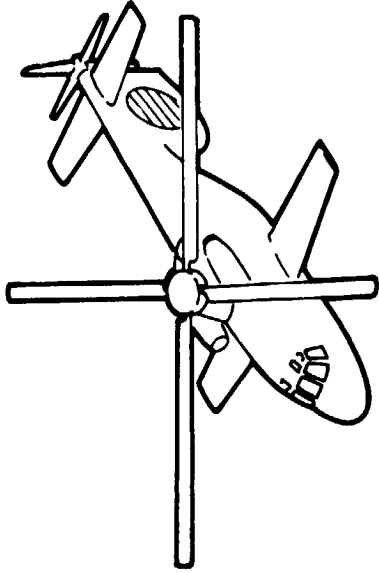
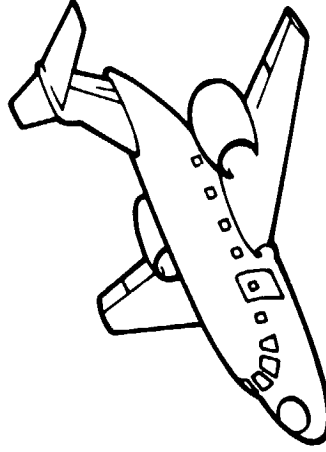


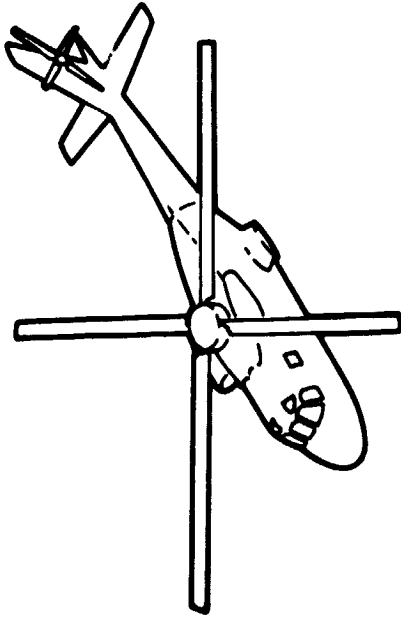
Figure 11.- Payload/range performance of North Sea helicopters.



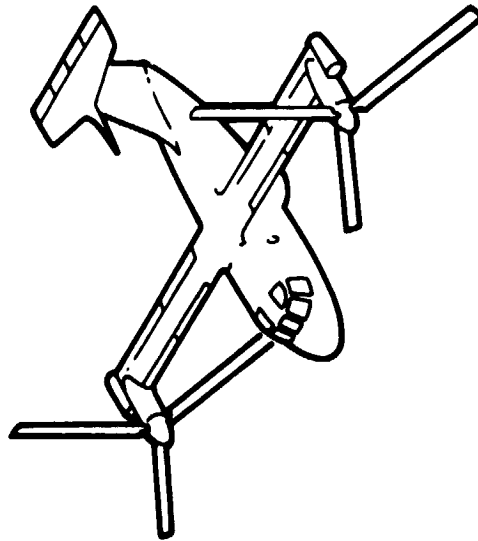
COMPOUND HELICOPTER



LIFT/CRUISE FAN



HELICOPTER



TILT ROTOR

Figure 12.- Advanced VTOL aircraft concepts.



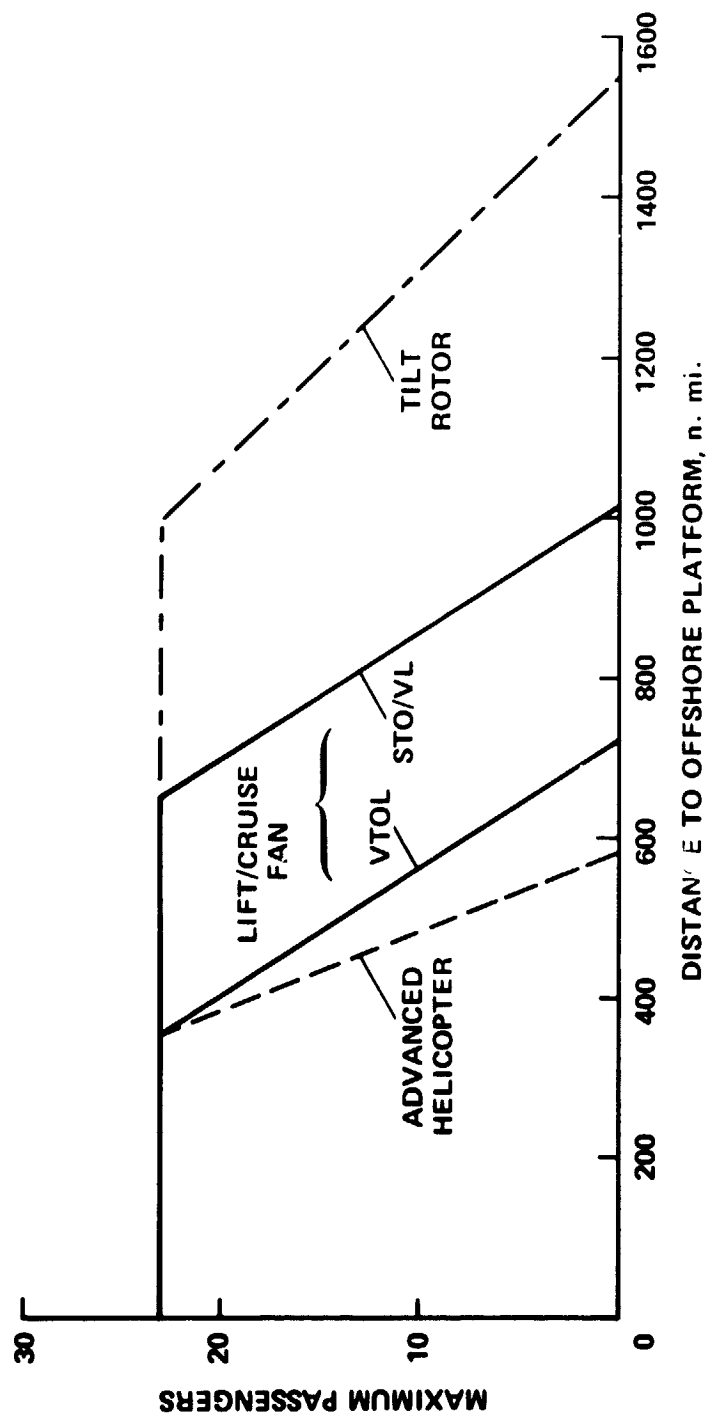


Figure 13.- Payload/range comparison for advanced VTOL aircraft.

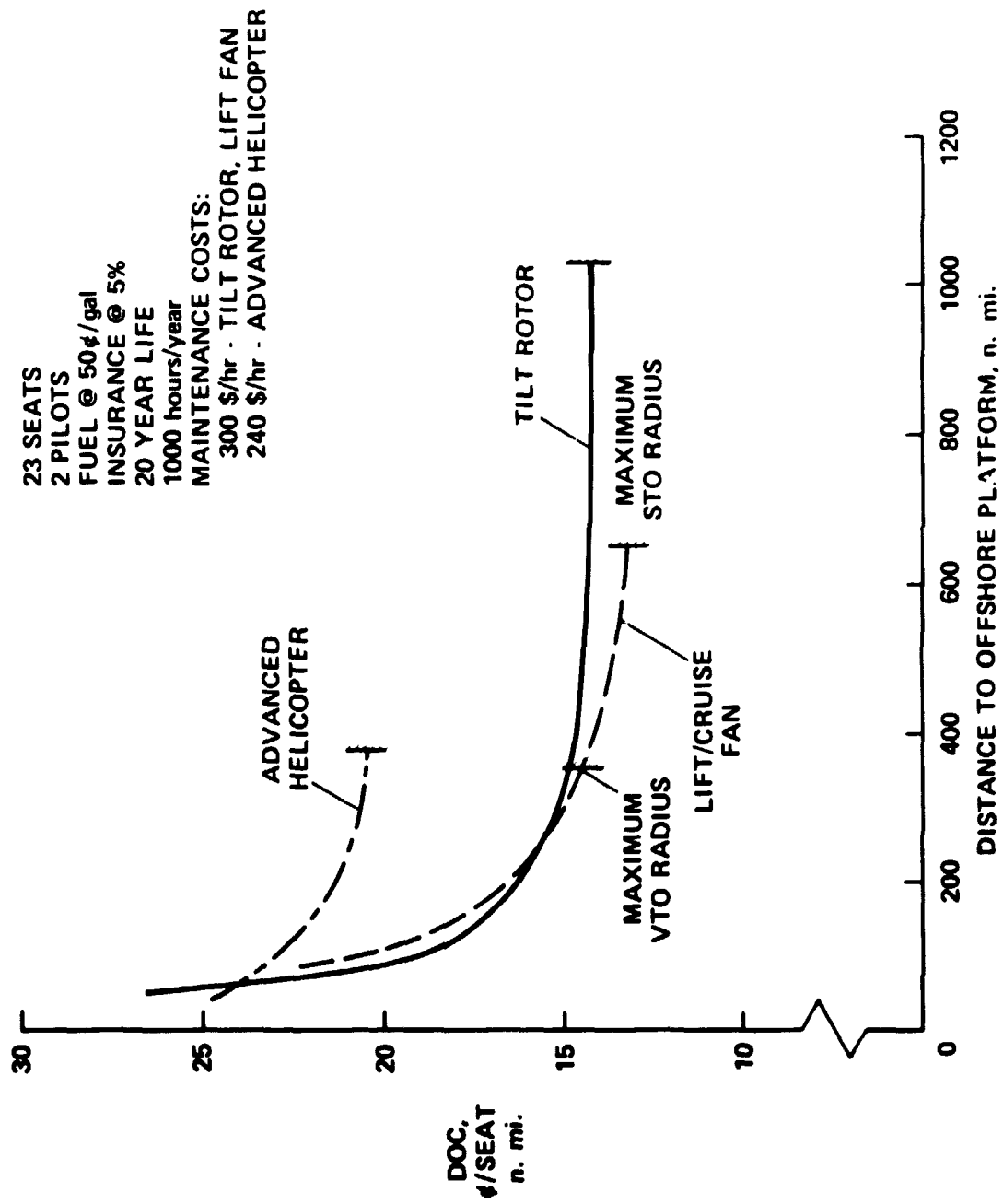


Figure 14.- Direct operating cost comparison.

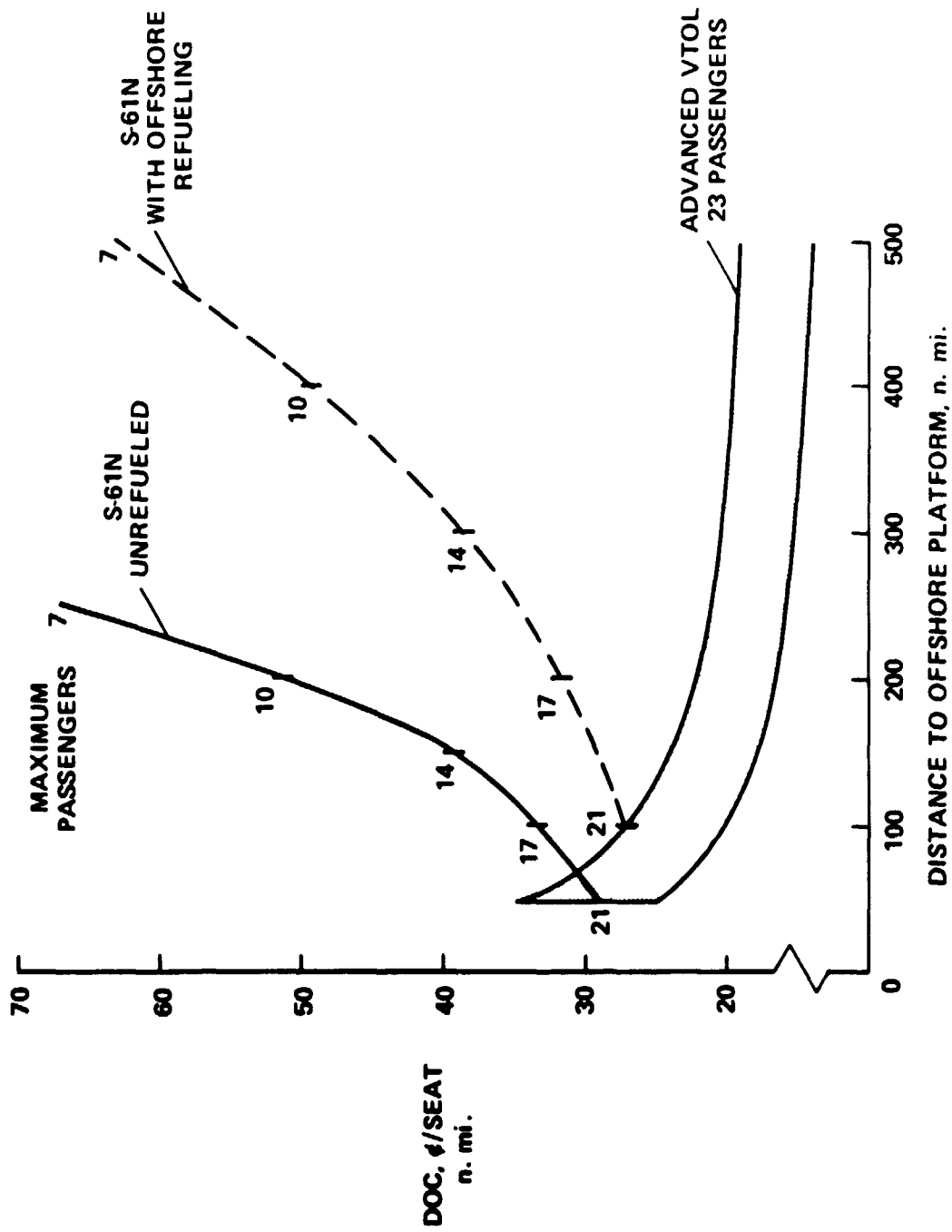


Figure 15.- DOC vs. offshore distance.

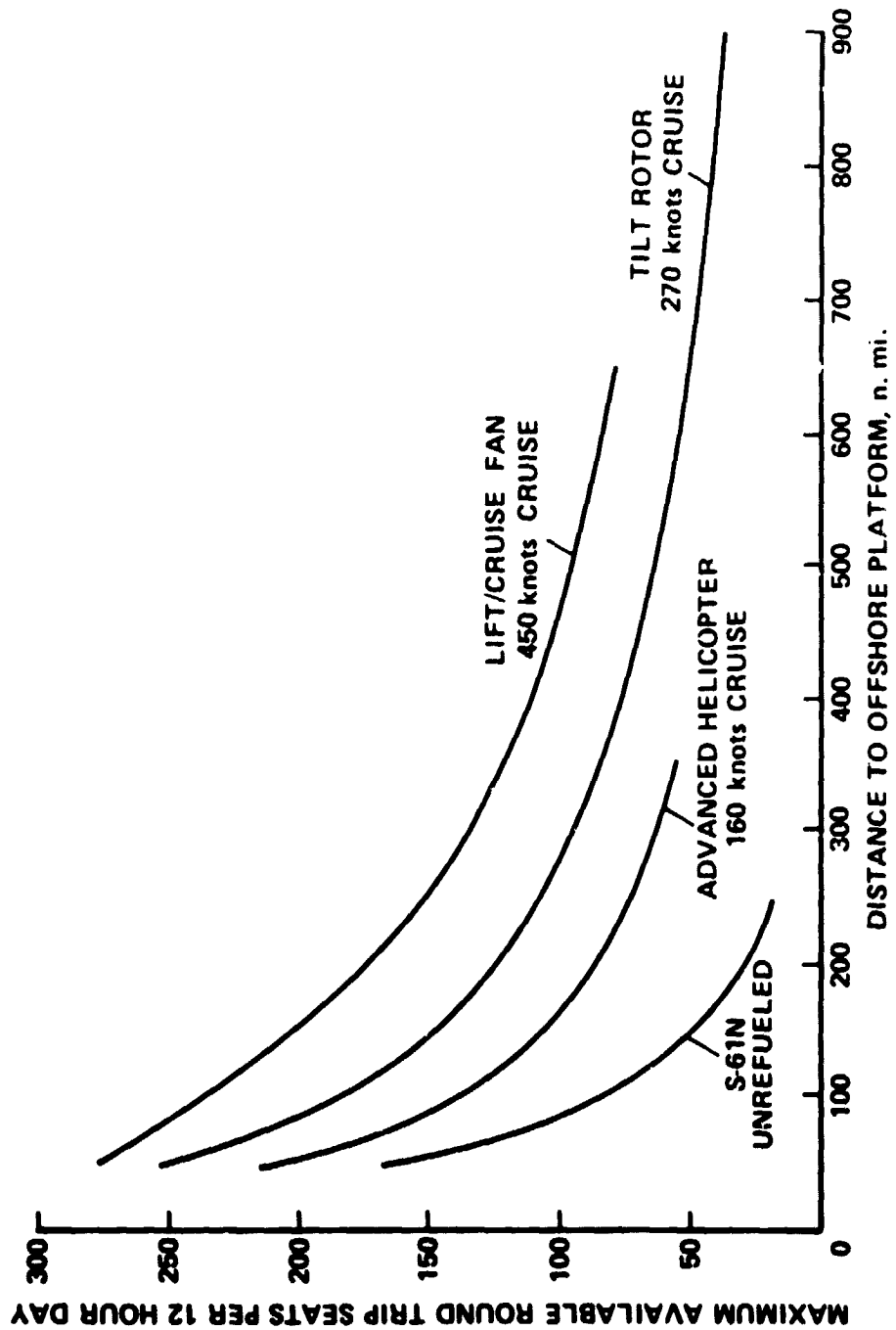


Figure 16.- Productivity of S-61N and advanced aircraft.

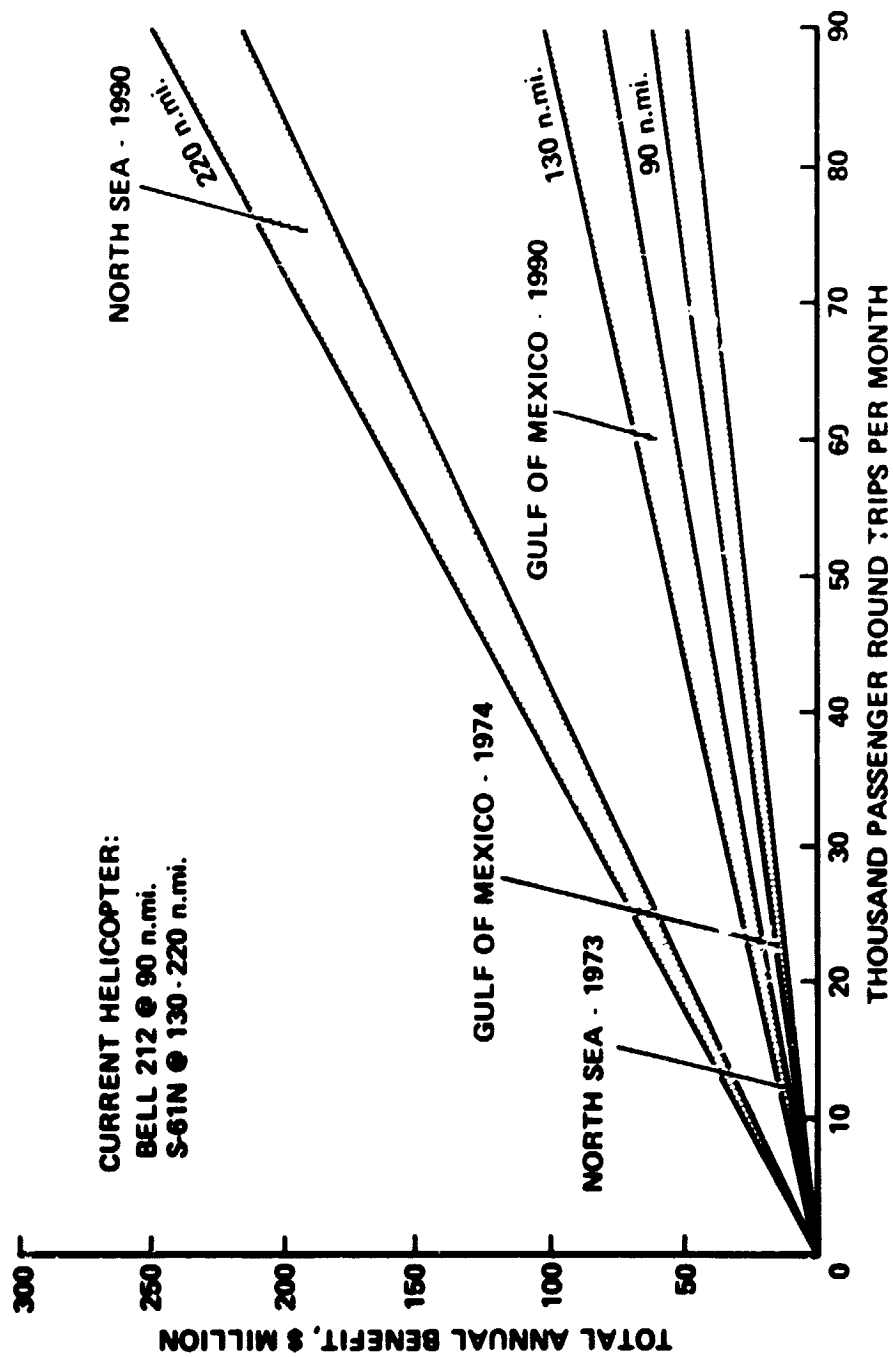


Figure 17.- Total annual benefit of advanced VTOL aircraft vs. passenger demand and offshore distance.